HOW DID WE GET HERE?

SPIRIT OF INQUIRY, HISTORY, EXPLORATION, MUSEUMS, PASSION, EDUCATION, FREEDOM OF THOUGHT

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INVENTIONS, ADVANCES, SPECIALIZATION, GLOBALIZATION, KNOWLEDGE GAP, SCIENCE TODAY

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CONSEQUENCES, RESPONSIBILITIES, SOLUTIONS, COMMUNICATION, COLLABORATION, OUTREACH

INCREASING SCIENTIFIC LITERACY
A SHARED RESPONSIBILITY

G. WAYNE CLOUGH, SECRETARY

Smithsonian Institution

CONTENTS

EXECUTIVE SUMMARY

WHEN OUR NATION EMERGED from World War II as the world's leading superpower, our role was most evident in the power of our military and economy. Undergirding our leadership in both were the world's most vibrant educational system and research and development enterprise. Nowhere was our unrivaled science and technology enterprise more clearly illustrated than by the Apollo manned missions to the moon, an accomplishment yet to be duplicated. Little did we realize that this remarkable time of pride in the achievements of American scientists and engineers may have represented the peak of our collective interest in, and understanding of, science and technology.

Fast forward to today. The rest of the world is closing the gap on our scientific and technological prowess as other nations, especially the growing powers of China and India, invest billions of dollars in research and development and education. At the same time, we struggle with the quality of science education in our schools, a lagging interest in science and engineering majors in our universities, controversies about topics like evolution and climate change, and evidence that scientific literacy is declining in our populace.

Is scientific literacy important? Is it urgent? A resounding yes to both questions! Science and technology underpin our economy, our ability to support our growing population, and new developments to keep us healthy and our military strong. Without scientific literacy, both in today's adult population and in generations to come, our nation stands to lose its ability to compete on a global scale. The future of our youth depends on their fluency in science in a world where employers seek well-educated, well-rounded individuals. Even our own ability to survive as a species depends on understanding the threats to our ecosystems and the choices we can make to mitigate these threats.

SCIENTIFIC LITERACY IN AMERICA

Scientific literacy: an appreciation of the basic principles of science and its methodology and an understanding of what scientific research produces.

- The United States placed 17th on the 2006 Program for International Student Assessment test given to 15-year-olds in the world's 30 wealthiest nations to measure their ability to apply math and science knowledge in real-life contexts.
- A 2009 national survey by the California Academy of Sciences indicated that only 59 percent of adults knew that early humans did not coexist with dinosaurs; only 53 percent knew how long it takes the Earth to orbit the sun; only 47 percent could give an approximation of how much of the Earth's surface is covered with water; and only 21 percent knew all three of these things.
- According to Michigan State University Professor Jon Miller, who has been measuring scientific literacy worldwide for the past 30 years, only 28 percent of Americans are scientifically literate.

The practice of science stretches back more than 400 years, and for the first two centuries or so it was possible for one individual to comprehend the whole body of scientific knowledge. More recently, however, scientific knowledge has grown rapidly, spawning hundreds of distinct fields, each of them understood by fewer and fewer people. We now live in an era of the exponential expansion of esoteric scientific specialties. Research and development is now a global enterprise fueled by more than $1 trillion of annual investment, and an estimated 1,200 exabytes of data were projected to be created in 2010.

As overburdened, underfunded educational institutions struggle to comprehend and teach the exploding body of scientific knowledge, it is no wonder that our graduates are not gaining the knowledge base they need to keep up with, much less lead, the rapid advances of a global scientific enterprise. How can ordinary citizens attain scientific literacy in such an environment?

Americans have typically sought to stay abreast of scientific breakthroughs and advancements through the news media, and science writers make an important contribution to helping the public understand complex issues. The "Science Times" section of *The New York Times; National Geographic* magazine; and PBS's "Nature," "NOVA," and "Scientific American Frontiers" programs are good examples. However, as fewer people rely on traditional media outlets for information, they have been forced to scale back, often reducing the coverage given to science and technology news. The circumstances beg for new approaches if we are going to make significant improvements in scientific literacy.

Americans increasingly look for information through the Internet, and the same powerful digital communications that threaten to overwhelm us with information should be turned into potent tools to provide relevant knowledge. Our youth are already highly reliant on technology to communicate, find information, and learn, offering an opportunity to reach a growing swath of the American public in new ways. No one can, or needs to, know it all, but everyone should be able to access what they need when they need it. Communications technologies are also a means to make learning about science interactive, personal, and engaging.

This solution requires a rethinking of our institutions, and we have begun that process at the Smithsonian. The Smithsonian Institution is committing its intellectual resources and convening power to help improve scientific literacy in America. Our new strategic plan directs us to make education a top priority for the entire Institution. We will help the public see beyond the silos of ever-narrowing fields of study, take advantage of digital technology to make our vast collections more accessible, coordinate our network of science centers, open the door for direct interaction with our scientists and researchers, provide formal training for the nation's teachers to help them make the best use of our scientific resources, and send resources for science education into our nation's classrooms.

Even though the Smithsonian has much to offer, the challenge of scientific literacy is far greater than one institution. We must commit ourselves as a nation to bringing science back into the public dialog, and as we do so, turn down the heat on long-simmering issues that have become flash points for demagoguery. Addressing the gap in public understanding that surrounds science will require the coordinated participation of scientists, educators, parents, media, and public institutions to find clear, compelling ways to communicate science. Many corporations, agencies, nonprofits, and educational entities have begun to work on the problem of scientific literacy, but their impact is limited because of a lack of coordination.

One place to begin is to call on our scientists and engineers to close ranks with educators, and engage in a public dialog that provides greater clarity about how their work contributes to the larger societal context of the nation's needs and interests. Today's scientists and engineers are specialists in narrow fields of knowledge and they need help if they are going to communicate effectively with those outside their disciplines. Universities, federal agencies, nonprofits, and industry can assist by training their scholars to communicate and rewarding excellent communication. The American Academy of Arts and Sciences has recently taken on this challenge and provides useful guidance through its publications.

Universities have a built-in capacity to advance scientific literacy. They can reach alumni and other audiences using digital technologies, improve the understanding of science among non-science majors, and give science and engineering students a broader perspective on their responsibilities as citizens. Additionally, universities can more fully explain the findings — and consequences — of faculty research to the public whose tax dollars fund their work, and coordinate faculty outreach to local schools to help improve K–12 science education.

Public museums represent a virtually untapped resource for increasing scientific literacy. More than most educational institutions, museums are focused on the transmission of general knowledge, which can be particularly effective in helping provide a broad understanding of issues. With their varied collections and exhibitions, reservoir of expertise, and ability to attract family and school groups, museums are a perfect venue for conducting informal education and assisting an overburdened educational system.

Nonprofit professional organizations and government agencies like the National Science Foundation and NASA are another resource in the efforts to improve scientific literacy. Many already have efforts underway to help with science education in K–12, but these are often fragmented. Working together within a strategic framework, these organizations could make a major difference in scientific literacy.

The role of parents cannot be underestimated in helping children learn about math and science. Surveys show that the large majority of parents are in agreement about the importance of math and science, because they appreciate the value of such knowledge in today's economy. Although religious beliefs occasionally may come into conflict with the findings of science, open discussion in our schools should be encouraged in an attempt to find common ground.

We have resources to address the challenge of scientific literacy, but we need a coordinated, strategic approach to deal with it effectively. Linking the efforts of the many organizations and groups who should be shareholders would represent a new and valuable step. Fortunately, we also have at hand new digital technology that can revolutionize both the presentation of information and the way we access it, as well as a new generation of users who have embraced it and represent a ready audience. Today's technologies allow knowledge to be parsed between what is needed to be scientifically literate in a general sense and the specific knowledge required for deeper exploration of a particular subject. Technology also opens a new realm of access to museum collections, archives, university classes, and knowledge-based offerings by nonprofit and for-profit organizations undreamed of in the past. Beyond the information itself, technology provides remarkable avenues for scientists, engineers, and educators to interact and work in teams, not only in our neighborhoods, but around the world. The possibilities are almost unlimited and need to be part of the way we address scientific literacy.

OUR NATION IS AT A CRITICAL JUNCTURE. The times demand that we use all of the tools we have to improve our students' scientific literacy. To successfully open a dialog with those who are doubtful about science, we must speak clearly about the benefits and risks in scientific advances. We must listen carefully to those outside the science enterprise and recognize that there is no monolithic viewpoint. If people and institutions have the will, then we can turn the tide for scientific literacy. Time is not our ally, and action is needed now. At the Smithsonian, we are prepared to take it.

INTRODUCTION
PUTTING SCIENCE BACK IN THE PUBLIC DIALOG


AT THE
ZOO

INTRODUCTION
PUTTING SCIENCE BACK IN THE PUBLIC DIALOG

WHEN DID THINGS get so complicated? I date it back to the 1960s, when people began saying "This isn't rocket science," about something that should have been simple but was not. The assumption was that "rocket science" was so complicated that only a "rocket scientist" could understand it. Of course, most of those who really made rockets and got them to do incredible things were engineers, not scientists, but the saying stuck. Somewhere in the 1960s and '70s, things that used to be understandable began to get away from us.

I was in the final year of my Ph.D. studies at the University of California at Berkeley when astronaut Neil Armstrong became the first man to walk on the moon in 1969; my fellow students and I toasted the event with a beer at LaVals Pizza, a local watering hole. That Apollo moon mission was broadcast live worldwide, and Americans shared the pride in the remarkable achievements of our scientists and engineers. Little did we know that this unique time may have marked the high point of the American public's respect for scientists and engineers as well as its interest in understanding science and technology.

SCIENTIFIC LITERACY IS AN URGENT AND IMPORTANT ISSUE. WHY SHOULD WE CARE? THE ANSWER IS SIMPLE: OUR WAY OF LIFE AND OUR SURVIVAL ARE AT STAKE.

After graduating from Berkeley, my 40-year career began; I worked first as an engineering professor and practicing civil engineer, then as an academic administrator and university president, and finally came to my current position as secretary of the Smithsonian Institution. In all these roles, nothing prepared me for the experience of standing before an unreceptive audience as I tried to explain the technical reasons why a sewer tunnel needed to be built, or for seeing people break down in tears when they related how a levee they thought was safe failed to protect their home during Hurricane Katrina. You empathize with the teacher who tells you that she cannot teach about climate change in her classroom for fear a parent will take umbrage, and you feel frustrated by your inability to help. Each of these experiences is indicative of how we perceive science and technology, scientific literacy or the lack of it, and the challenges involved in communicating complex issues to the public. These challenges have become more difficult over time as understanding of science has declined.

Scientific literacy is an urgent and important issue. Why should we care? The answer is simple: Our way of life and our survival are at stake.

This nation's high standard of living depends directly on the scientific literacy — defined broadly as an appreciation of the basic principles of science and its methodology and an understanding of what scientific research produces — that has given us the competitive edge over the past 30 to 40 years. America's investments in scientific and engineering research in the 1960s, '70s, and '80s gave us personal computers, the Internet, cures for diseases, advanced telecommunications, and a longer lifespan, to name just a few examples. Today, other nations are emulating our course and steadily improving their ability to compete with us. The best jobs are moving to those nations where education in math and science is strong and valued. Critical decisions we must make also rely on our understanding of science and technology. How do we handle climate change? Will we invest in alternative fuels? How will we repair our decaying infrastructure? Under what circumstances will we allow genetic engineering to be used in food technology and for medical developments? How can we address serious environmental issues in a way that makes sense?

Many Earth and atmospheric scientists assert that the planet has entered a new geological time period — the Anthropocene — whose name is a combination of Greek roots meaning "human" and "new."[1] The Anthropocene is described as a time when human activities have such a profound impact on the environment that they become a primary driver of change in the Earth's natural systems. In essence, our survival as a species is now in our own hands. Yet too few Americans have the background needed to appreciate the choices we face.

Many reasons help to explain why we find ourselves where we are. One is that the present generation of scientists for the most part is unable, or unwilling, to engage in the necessary public dialog. A recent study noted that "when it comes to persuading the American public about some of the most controversial issues of our time, today's scientists too often get failing grades."[2] For example, Gallup polls show that only 39 percent of Americans believe in evolution, one of the lowest percentages in the developed world.[3] Recent court rulings assert there is no scientific evidence that vaccines cause autism, yet far too many parents cling to that dangerous belief and refuse to have their children vaccinated. Contrast these findings with the National Science Board's *Science and Engineering Indicators 2010,* which reports that 80 percent of Americans claim to be very or moderately interested in new scientific discoveries.[4]

If the interest is there, why are perceptions so far off the mark? Who will clearly explain new discoveries to the public — and to policymakers? Everyone in the scientific community, including all of us at the Smithsonian, must do a better job.

EXPONENTIAL SCIENTIFIC GROWTH INCREASES COMPLEXITY

In the years since World War II, knowledge has expanded to the point where hundreds of disciplines have been created to accommodate it. Increased specialization sharpens our field of vision, but ever-narrowing areas of study also make it more difficult for the average person to understand not only the science, but even the context for new discoveries. These circumstances are exacerbated by advanced digital communications systems that hurl a huge and increasing volume of information at us at speeds that may seem dizzying now but will only increase in the future.

Today, the frustration level has become so high that it is the stuff of comedy. Tom and Ray Magliozzi, better known as Click and Clack of National Public Radio's "Car Talk," help us with the seemingly impossible task of diagnosing problems with automobiles that apparently have no reparable parts. The brothers' advice about cars is couched in humor-based therapy sessions that help us feel better about bringing our car to the shop. Of course, this expression immediately dates me. No one takes a car to the shop any more, but rather to customer service, where, prepared for the diagnosis by Click and Clack, we are relieved to learn that the problem is a software glitch in the computer control for our windshield wipers. The whole situation was captured in the classic book, *Zen and the Art of Motorcycle Maintenance* by Robert M. Pirsig, in which the protagonist is driven into a psychological crisis over the inability of our modern world to write a set of instructions that would enable an average person to assemble a toy for a child's birthday.

In essence, the current hyper-specialization and speed of information flow has led to a divorce between the average person and the experts who are capable of understanding the problem. The maxim "never trust an expert," attributed to Lord Salisbury, who was prime minister of Great Britain in the latter part of the 1800s, has advanced into the lexicon of common wisdom. The experts themselves have become so specialized that few are able to tackle the broader, multi-dimensional problems that people see as important.

At the other end of the scale, our educational institutions are failing to help our citizens understand and appreciate science and technology. Our K–12 system historically has struggled to teach the basics of science, and now faces even greater challenges as budget cuts reduce the number of teachers and the opportunities for field trips and new equipment. The result is graduates who are not equipped with the knowledge base they need to stay in touch with the rapid advances of a global scientific enterprise.

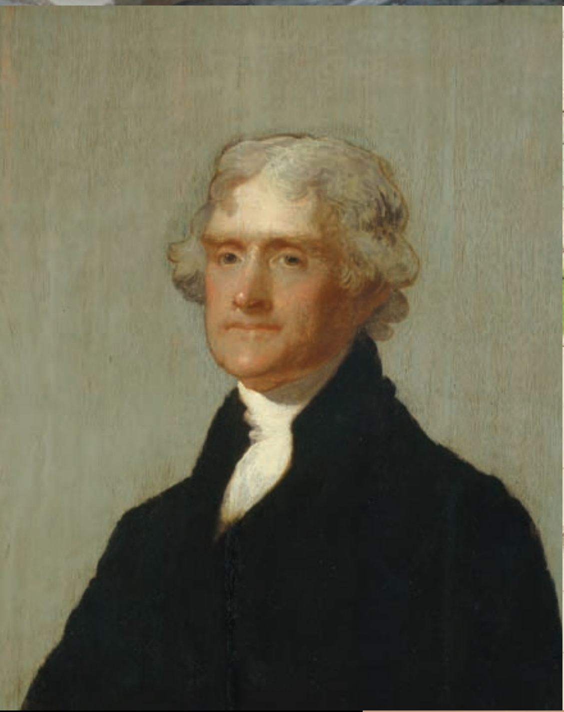
We face a widening gulf, and time is of the essence in addressing it. The circumstances are daunting, but we can make a difference if we take action. We should begin by reinventing our educational models to use the technology that has become ubiquitous, particularly among our youth. For the first time, digital technology offers us an opportunity to deliver exciting and inspiring educational materials about science and technology in ways that allow learners, teachers, and scientists to interact as a community and that open access to resources such as scientific collections that have heretofore been invisible to the public. However, getting the job done will require cooperation. The task ahead is too large to be done piecemeal and requires all parties to work together in building a national approach.

WE NEED TO FOSTER PUBLIC DIALOG ABOUT SCIENCE THAT BREAKS DOWN WALLS, RATHER THAN BUILDS THEM.

Even as we implement a new national strategy to use educational technology in the interest of scientific literacy, we must also address the communication issues related to the growing specialization of science and the overwhelming flow of information. We need to foster public dialog about science that breaks down walls, rather than builds them. Beyond the collaboration of educational institutions, this dialog must also include parents, science organizations, museums, media, and scientists and engineers themselves. Each group has to accept its responsibility to contribute to the dialog if we are to succeed in finding common ground and moving forward.

Scientific literacy is rapidly becoming one of the great issues of our day, and the sooner we recognize the problem, the sooner we can begin to build the national effort needed to address it. The Smithsonian Institution, with its intellectual resources and its power to convene experts and engage laypeople, is poised to do — and committed to doing — more.

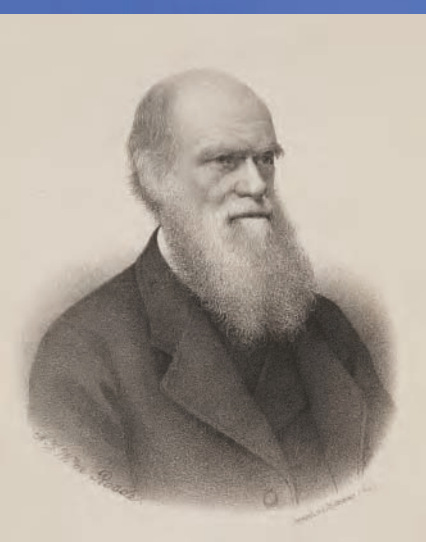
CHAPTER ONE
THE EMERGENCE OF SCIENCE IN THE UNITED STATES









CHAPTER ONE
THE EMERGENCE OF SCIENCE IN THE UNITED STATES

SCIENCE AS WE KNOW it today, and the institutions that support it, have their roots in the Age of Enlightenment, a period that began in the mid-1600s, ended in the early 1800s, and launched a series of remarkable advances in science and technology as well as the arts.

Optimism reigned during the Enlightenment, and new experiments in government, including our own, allowed an expression of ideas never before possible. Expeditions to the far reaches of the globe brought improved scientific understanding, while stories of derring-do by scientist-explorers, who told fascinating tales of their encounters with exotic people, creatures, and plants, captured the public imagination. Society enjoyed the benefits of science, ranging from better-lit streets and homes, new forms of transportation, and cleaner water supplies to an overall improvement in quality of life and the economic growth of nations.

Relative to now, it was also a simpler time. The world's population stood at fewer than one billion[1], compared to seven billion[2] today, and the knowledge base was small. As many as three quarters of the world's people were farmers,[3] deemed to need only enough education to conduct their daily work. Science and engineering — as we know them today — did not exist, and the few people who were privileged to attain a university education could master the elements of all that was known about engineering and science, and even the arts, if they were so inclined.

Philosophically, western thought enshrined the importance of the individual and emphasized the value of freedom of choice. Governments incorporating democratic principles arose, most strikingly in the new nation of the United States, the leaders of which — including Thomas Jefferson, Benjamin Franklin, John Adams, and George Washington — were all well versed in the philosophical principles of the Enlightenment.

With its emphasis on the individual and democracy, the Enlightenment opened the door for men and women who were not wealthy to play their part, deepening the talent base and adding common sense derived from life experience to the recipe.

FROM WARFARE TO CIVIL WORKS AND PRACTICAL IMPACT

Before the Enlightenment, the fruits of science and engineering largely benefited the military and advanced the causes of kings, emperors, czars, dictators, and their governments. From the time of the Roman Empire, engineering was a key to military success, providing weapons, advanced fortifications, and the roads that allowed the Empire to control its extended territories. During the Renaissance, Leonardo da Vinci served his patrons not only with artwork, but also by using his understanding of mechanics and leverage to design weapons. Few weapons systems lasted long, however. For every new weapon, a counter weapon was created. The armor of legendary kings and knights was made obsolete by the penetrating power of arrows launched from the longbow, which in turn was trumped by the onset of firearms. The continual development of new weaponry reached an apex in the American Civil War, when killing power outpaced both conventional battle tactics and the ability to protect and medically treat soldiers. As a result, soldiers were slaughtered in numbers unheard of in all previous wars, and still larger numbers died of festering wounds and from unsanitary conditions.[4]

The French government changed the focus of science and engineering from waging war to improving cities by organizing military engineers to build roads and canals for civilian purposes. This application of technology opened new horizons for average citizens, and in 1747, the French government created the prestigious École Nationale des Ponts et Chaussées, the oldest civil engineering school in the world, to educate young men to build civil works. The school believed students should be "generalists," who combined strong technical skills with knowledge of management and the humanities. As a result, Ponts et Chaussées graduates advanced from the technical ranks to leadership roles in business and government. Other *grandes écoles* followed as new fields developed to apply the benefits of technological advances to civil society. France owes its outstanding infrastructure to the work and research of the subsequent generations of graduates of the *grandes écoles.*[5]

The Enlightenment scientists were also generalists, whose formal education, if they had any, was focused on the classics. Science was considered an aspect of philosophy, the purpose of which was to discern the meaning and ways of life and the world. Personal inclination led some Enlightenment thinkers to focus on observing and chronicling the natural world, applying the scientific method devised by Francis Bacon in the early 1600s, in an effort to decipher its riddles. Such scholars were known as natural philosophers. It was not until 1840 that the word "scientist" was coined by William Whewell, himself a theologian and philosopher as well as a scientist.[6] These early scientists compensated for the lack of scientific institutions and curricula by networking with each other through letters and visits, and forming societies where they presented and debated new discoveries.

THE COUPLING OF INTOXICATING DISCOVERIES WITH TANGIBLE APPLICATIONS THAT BENEFITED SOCIETY LED TO PUBLIC SUPPORT FOR SCIENCE AND TECHNOLOGY.

Discoveries during the Renaissance, the Enlightenment, and the years immediately following shed light on natural phenomena that previously had defied understanding, and, in the process, created new fields of study. As the knowledge base rapidly expanded in particular areas, specialties began to emerge, including chemistry, astronomy, and the early "ologies" — anthropology, geology, biology, and physiology.

Isaac Newton (1643–1727) published *Principia Mathematica,* describing universal gravitation and his three laws of motion. Joseph Priestley (1733–1804) discovered oxygen and its importance to respiration in living beings. Benjamin Franklin (1706–1790) proved that lightning was electricity. William Herschel (1738–1822) extended the boundaries of the known solar system with the discovery of Uranus. William Smith (1769–1839) applied stratigraphy to produce the first geologic map of England. German polymath Johann Wolfgang von Goethe (1749–1832) was the first to systematically study human color perception.

Many of these remarkable scientists were trained or educated for other pursuits and excelled in them as well as in science. Franklin, who was largely self-taught, was a successful printer and the foremost diplomat of the fledgling United States. Smith learned his geology on the job as a miner and surveyor. Priestley was a minister who founded the Unitarian Church. Herschel was a musician who supported his development of new telescopes with income from music lessons and performances. Goethe was an author renowned for poems and plays that rival Shakespeare's.

The Enlightenment scientists met with the most acclaim when their wide-ranging interests found practical application. One of the greats of English science, Humphrey Davy, was lionized in 1815, when he used his knowledge of chemistry and combustion to create the Davy Safety Lamp, which provided illumination in coal mines without igniting coal gas.[7] With a few exceptions, the coupling of intoxicating discoveries with tangible applications that benefited society led to public support for science and technology.

SCIENCE TAKES HOLD IN THE UNITED STATES

The work of science and engineering developed rapidly in the well-established societies of Europe and England, where a telescope and a collection of natural curiosities were requisites for any civilized drawing room; but life in the American colonies was focused on survival and developing a social order and an economy. The few existing universities, founded to educate young men for the ministry, emphasized the classics and religion. Established in 1636 as the nation's first institution of higher education, Harvard University was a private institution affiliated with the Congregational Church, and until 1708 its presidents were ministers.[8] The College of William and Mary, founded in 1693 as the nation's first public university and supported by tax revenues, was affiliated with the Church of England.[9] Until the early 1800s, William and Mary remained the only university in the Commonwealth of Virginia.

The limited opportunities for university study, and the narrow focus of available curricula, meant that most affluent Americans traveled to Europe for higher education. For those without means, self-education was the only alternative, and it generally took practical form. Maria Mitchell (1818–1889), the nation's first professional woman astronomer, noted that her American colleagues were either poor schoolteachers, who fashioned rudimentary telescopes in response to students' curiosity, or the makers of clocks and navigational instruments, who used the stars as determinants of time.[10]

Nevertheless, the new ideas and discoveries of the Enlightenment had a profound impact on the thinking of America's founding fathers. Benjamin Franklin and Thomas Jefferson (1743–1826) were deeply intrigued by science. The expertise and accomplishments of these men, like their European counterparts, spanned numerous fields, and their scientific interests influenced their leadership of a newly emerging nation.

Franklin, son of a tradesman, was imbued from childhood with a sense of wonder and curiosity about nature and science. Using his knack for making and saving money, he bought books to educate himself. In time, he organized groups of young men who improved their minds through the exchange of ideas and books, an undertaking that spawned the first public lending library and the prestigious American Philosophical Society, which continues today.

Scholars rightfully make the case that Franklin was the foremost American scientist of his time. His scientific achievements included practical inventions such as the Franklin stove, bifocal glasses, and segmented hulls that made ships less prone to sinking. He also named the Gulf Stream, collected information about it from whalers and from personal observation, and published the first chart of it. Best known for his kite experiment, Franklin showed lightning to be an electrical phenomenon — a discovery that gained him international renown as European scientists initially scorned and then embraced his findings. A member of the Royal Society of London and the first person from the colonies to receive its prestigious Copley Medal, Franklin was awarded honorary degrees from the universities of Edinburgh, Oxford, and Cambridge. His scientific work afforded him access to the great leaders of England and Europe, which greatly increased his effectiveness as a diplomat for the new nation. Franklin deserves enormous credit for building the credibility of science and for the founding of institutions that allowed it to flourish.[11]

Fellow diplomat Thomas Jefferson shared Franklin's wide-ranging intellect but came to science with a broader perspective, thanks to his studies at the College of William and Mary. To paraphrase Mark Twain, Jefferson was careful not to let his university education (which included little science) get in the way of his learning. Jefferson was a lifelong learner whose scientific knowledge was largely the result of personal study and research, and he excelled in studies of biology, geology, and paleontology. He is quoted as saying, "When I was young, mathematics was the passion of my life," and "Nature intended me for the tranquil pursuits of science, by rendering them my supreme delight."[12]

JEFFERSON'S PASSION FOR SCIENCE RESULTED IN REMARKABLE DOCUMENTATION OF THE NATURAL WORLD AND ITS INHABITANTS IN NORTH AMERICA.

Jefferson wrote what is acknowledged as the first book on scientific geography in the New World, *Notes on the State of Virginia,* and was particularly proud to have been named president of the American Philosophical Society in 1797. That same year, he became vice president of the United States, and on his journey to take the oath of office as vice president, his wagon was loaded with fossil bones intended for the Society. His political opponents lampooned him as "Mr. Mammoth" for his interest in and display of fossils. I suspect that Jefferson considered it a compliment.

Like Franklin, Jefferson had his own share of discoveries and inventions, many of a practical nature. He is credited with improving the plow, developing a cipher to encode messages, and designing spectacles, including sunglasses. He was not without whimsy, demonstrated by the great clock at Monticello whose weights, made from cannonballs from the Revolutionary War, descend through holes from one floor to the next. The Smithsonian Institution is the proud owner of another invention, the Jefferson writing desk, at which he wrote the Declaration of Independence. About the size of an attaché case, this ingenious device has been dubbed "the 18th-century laptop" since it traveled on horseback and unfolded into a desk with multiple leaves and storage places. He was particularly proud that it allowed a writer to work on two pages at a time.[13]

Jefferson's passion for science resulted in remarkable documentation of the natural world and its inhabitants in North America. Convinced that the United States should expand westward, Jefferson engineered the Louisiana Purchase and then commissioned Meriwether Lewis to lead the Corps of Discovery, to explore not only the land recently acquired but that beyond it to the Pacific Ocean. Inspired by the famous expeditions of the English explorer Captain James Cook, which included scientists to observe and document the voyages, Jefferson knew that scientific knowledge from such expeditions was enormously valuable in identifying economic potential and in building consensus for territorial expansion.

In preparation for the expedition, Jefferson sent Lewis to Philadelphia for a year and a half to be educated by the leading scientists of the American Philosophical Society. The result was a careful inventory of the flora, fauna, and people the expedition encountered. Lewis and his partner, William Clark, identified some 120 species of animals and 180 species of plants[14] that for the most part were not previously known to science, and gained insights into the cultures of the many Indian tribes encountered along the route.

A NEW KIND OF PUBLIC UNIVERSITY

Jefferson's other great accomplishment beyond his work as a founding father of our nation was to design and establish the University of Virginia in 1819, an achievement that helped to realize many of his long-held and deep-seated beliefs.

As Governor of Virginia (1779–1781), and a member of the Board of Visitors for the College of William and Mary, he became convinced that the College should serve a larger purpose, namely educating the leaders of a new democratic and free republic. As a result, he advocated for moving William and Mary away from its religious identification with the Church of England toward a more holistic approach to education. He felt it should offer opportunity regardless of a person's birth or rank in society and sought to broaden courses of study to include the sciences and a more objective study of many faiths. As a powerful member of the College's Board of Visitors, Jefferson managed to eliminate its Anglican school of theology and won other small concessions. However, when the state legislature failed to approve the larger dimensions of his reforms, he began thinking about an entirely new kind of public university.

Building the University of Virginia was the last of three accomplishments Jefferson instructed his family to inscribe on his tombstone, following his authorship of the Declaration of American Independence and the Virginia Statute for Religious Freedom. The order was chronological, but Jefferson may also have wanted to make the point that each accomplishment built on the one before. Jefferson may have had his passion for education and discovery in mind when he included "the pursuit of happiness" in the Declaration's list of "unalienable rights." He consistently linked freedom with learning and may have seen the Declaration as a necessary frame for the University of Virginia.

In Jefferson's view, the University of Virginia would offer courses of study not only in the classics but also in the sciences, a new concept for higher education in the United States. In planning the curriculum, Jefferson prescribed literally dozens of science lectures, especially in chemistry, but also in zoology, botany, astronomy, and geology. He also stipulated books in these fields that he wanted in the university's library.[15]

In his design of the university, Jefferson also relied heavily on the Statute for Religious Freedom. He understood that religion was an important component of society, but believed that the state should not support one particular religion over others, particularly in a public institution of higher education. This belief continues to define the role of religion in state-supported universities in the United States today. It is an important consideration in the teaching of science, particularly when science brushes up against faith-based doctrines that some believers see as contradictory to scientific findings.

Jefferson's design for the University of Virginia reflected his fear of the overarching impact a state religion would have on free inquiry. To his core, Jefferson was a practical man. If the new nation was to survive, he believed, it had to provide basic educational principles to the young men and women who would lead it through trying times. If the country was to succeed against competing ideologies, Americans needed to know about the new and sometimes controversial ideas science produced.

In Jefferson's model, a university would teach the humanities and the sciences on their merits and debate and evaluate them in an environment free of coercion. Religion would have a place in the course of study but would be approached from a multi-denominational basis. Some of Virginia's religious leaders called this new institution a "godless university,"[16] and the debate became heated. The compromise was to provide places on campus where denominational groups could offer extra-curricular religious activities. This solution still holds at American public universities, where religious groups can have campus ministries, but only on property that they own.

The reasons for separating activities related to a particular religion from curricula at public colleges and universities remain poorly understood by the general public and even by faculty and students. The issue becomes even more charged and confused on topics such as evolution, where evidence from scientific inquiry can run counter to the views espoused by particular religious groups, or where concepts designed to bolster religious doctrines are posited as science. In Jefferson's view, confusing religious beliefs with science signaled an unwillingness to put ideas to the objective tests scientists used to find the truth.[17]

He held this view until the end; in a letter to John Adams in 1813 he wrote that the university was "now qualified to raise its youth to an order of science unequalled in any other state; and this superiority will be greater from the free range of mind encouraged there, and the restraint imposed at other seminaries by the shackles of a domineering hierarchy and a bigoted adhesion to ancient habits."[18]

THE BIRTH OF MUSEUMS BROADENS PUBLIC ACCESS TO LEARNING

The University of Virginia was an early indicator of the direction science would take in the 1800s, when growing scientific knowledge and new discoveries coalesced into useful institutions and courses of study. Even as Jefferson formed his new models for a nation and a university, an innovative form of public education emerged in England and Europe — the public museum. In the spirit of the Enlightenment, museums offered an opportunity for the public to learn from the collections of wealthy individuals and the artifacts gathered from great expeditions. The British Museum first opened its doors in 1759, while the Louvre was created in 1793 to exhibit the treasures accumulated by the French royal families. Museum-building soon spread to the United States; the Academy of Natural Sciences in Philadelphia welcomed the public in 1828, and the Boston Society of Natural History (now known as the Boston Museum of Science) did so in 1830. The late 1800s and early 1900s became known as the "museum age," because such institutions became a fixture for every aspiring metropolis.[19]

Around this time, the United States received word of an extraordinary bequest from an Englishman whose generosity would forever alter our museum landscape. James Smithson (1765–1829) was a son of the Enlightenment and an accomplished scientist. Smithson was the illegitimate son of the Duke of Northumberland, one of the wealthiest men in England. As a student at Oxford University, he became enamored of the new field of chemistry; he then furthered his studies at the University of Edinburgh. Smithson found that the principles of the Enlightenment were taken far more seriously there than they were at Oxford, where the Church of England was dominant and where students were more likely to be members of the upper class.

Smithson's work in chemistry led to a number of discoveries, as well as his induction into the Royal Philosophical Society at an early age. His travels were largely confined to Europe and England, but he nonetheless amassed an impressive collection of minerals, analyzing a form of zinc carbonate from Derbyshire and Somerset that was subsequently named smithsonite in his honor.

MUSEUMS OFFERED AN OPPORTUNITY FOR THE PUBLIC TO LEARN FROM THE COLLECTIONS OF WEALTHY INDIVIDUALS AND THE ARTIFACTS GATHERED FROM GREAT EXPEDITIONS.

Although he never set foot in the United States, Smithson followed its development with great interest. He admired its freedom of thought and was impressed that founding fathers Franklin and Jefferson were heavily involved in science and education. History documents no meetings between Smithson and Franklin or Jefferson, but they were contemporaries who spent considerable time in close proximity, shared an interest in science, and debated the issues of the day. Their paths may well have crossed, and it is intriguing to think so.[20]

Smithson bequeathed his estate "to the United States of America, to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." The bequest's announcement in 1836 deeply moved John Quincy Adams, former president and subsequent member of the U.S. House of Representatives, who served as a watchdog over the funds. Adams made countless speeches to generate public support for this new institution and kept a firm hand on the eight-year debate over the form it would take. Ideas were plentiful in a young nation whose capital was bereft of institutions, and everything was considered — a national university, observatory, library, and even a large farm to demonstrate agricultural methods. In the end, the Smithsonian was placed in the hands of scientists and authorized to open in 1846.[21]

The Smithsonian's first secretary, Joseph Henry (1797–1878), was one of most accomplished scientists in the United States. Largely self-educated, he came to the Smithsonian from Princeton University, where he had been a professor of physics with an interest in electromagnetism. Credited with the invention of the electric motor, simultaneously with Michael Faraday, Henry was one of the first to demonstrate that passing an electric current across a wire could cause an electromagnet at the wire's end to sound a bell, work that formed the basis for Samuel Morse's telegraph.[22]

The new institution Henry was creating was without precedent. Neither fish nor fowl, neither university nor museum, the Smithsonian was something in-between. As the Institution was the only broad-based federal science agency of its time, its secretary was sought after by government officials for advice on science issues. Henry quickly grew beyond his background in the physical sciences to become knowledgeable about biological sciences, Earth sciences, and astronomy, as well as arts and culture.

In addition to developing a science capability at the new institution, Henry was intrigued by the idea of predicting weather, something that was critical to the nation's agricultural, defense, and transportation sectors. At that time, there was no national weather service and little understanding of how weather systems moved across the country. Henry enlisted citizens living near telegraph stations across the nation to transmit regular readings from thermometers and barometers to Washington. From the data, he developed national weather maps showing cold fronts arising in the west and moving east. His efforts — one of the first organized uses of what we now call "citizen science" — led to the creation of the National Weather Service.[23]

Henry built the Smithsonian into an institution with a worldwide reputation for science and worked with Abraham Lincoln to promote science on a national level. While few may associate Lincoln with science, he was an interested observer and remains, in fact, the only U.S. president with a patent (in his case, for a device that enabled a cargo boat to push itself over sand bars).[24] Lincoln's work as a lawyer for the railroads had whetted his appetite for science and technology as he saw firsthand the substantial technological advances the industry made while connecting the far-flung reaches of a growing nation. This experience led him to authorize the construction of the transcontinental railroad even as the Civil War raged.

Lincoln relied on Henry to advise him on science, and it was a rich partnership. Lincoln even used one of the towers of the new Smithsonian Castle to view the Civil War armies arrayed on the battlefields of Northern Virginia. Henry and Lincoln helped create the National Academy of Sciences, America's premier science organization, with Henry serving as the Academy's second president.

Henry was no stranger to the controversies science generated. For example, he was familiar with Charles Lyell's (1797-1875) *Principles of Geology,* which argued that the very same processes observed by modern man had been slowly changing the Earth in momentous ways over long periods of time.[25] This breakthrough in thinking explained many of the phenomena that until then had puzzled scientists. However, it required scientists to envision the Earth as having been formed over millions, if not billions, of years, a controversial concept to those whose religious doctrines described a far younger world. Among those fascinated by Lyell's findings was a young Charles Darwin, who took *Principles of Geology* along when he set sail on the *Beagle* in 1831.

As secretary of the Smithsonian, Henry was surrounded by growing collections of fossils that were millions of years old. As a devout Christian, he was called upon to reconcile the findings of science with the interpretations of the Bible. In an address on the issue, he pointedly stated that the findings of science did not contradict Christianity but supported it. The more wondrous nature was found to be, he said, the more God's hand could be seen in the making of it. When Darwin published *On The Origin of Species* in 1859, Henry was impressed by Darwin's arguments and encouraged publishers to print copies for the U.S. market. For Henry, the findings of scientists such as Darwin did not contradict the beliefs of religion, since the two were fundamentally different.[26]

JOSEPH HENRY BUILT THE SMITHSONIAN INTO AN INSTITUTION WITH A WORLDWIDE REPUTATION FOR SCIENCE AND WORKED WITH ABRAHAM LINCOLN TO PROMOTE SCIENCE ON A NATIONAL LEVEL.

After Henry's death in 1878, accomplished ornithologist and ichthyologist Spencer Baird (1823–1887) became the Smithsonian's second secretary and took the Institution to the next level. Under his leadership, the science collections grew rapidly and the Smithsonian constructed the first national museum, now known as the Arts and Industries Building. The third secretary, Samuel Pierpont Langley (1834–1906), strengthened the Smithsonian's programs in astronomy and aerospace science.

As the nation matured, other federal agencies and a network of universities began to emulate these scientific efforts. The Smithsonian was maturing as well, adding collections and museums in art, history, and culture. This breadth of perspectives is one of the Smithsonian's great strengths, yet thanks to the groundwork laid by Henry, Baird, and Langley, the Institution remains firmly rooted in science.

LAND-GRANT UNIVERSITIES BLEND PRACTICAL EDUCATION WITH LIBERAL ARTS

While the Smithsonian was developing one model of public education, universities were beginning to focus on technological outreach and scientific research in a different way from Jefferson's model for the University of Virginia.

Prior to the Civil War, universities were relatively rare in the United States, and few of them were oriented toward what might be called national needs. Fewer still had a strong focus on science or engineering; the principal source of engineers was the military academy at West Point, whose curriculum drew on that of the *grandes écoles* of France.

However, the need for engineering talent grew as the nation entered the mainstream of the Industrial Revolution during the 1800s. Individual states began to respond. In 1855, both Michigan and Pennsylvania created colleges to meet the demand for talent and provide advice for the growing sectors of agriculture and industry. These colleges are known today as Michigan State University and Pennsylvania State University. Created in 1861, the Massachusetts Institute of Technology represented a new type of college with an emphasis on learning by doing and on integrating professional and liberal arts educations. The federal government noticed this movement toward mission-oriented colleges, and in 1857, Justin Smith Morrill of Vermont introduced a bill to create land-grant colleges, which would focus on teaching agriculture, science, and engineering. The bill provided grants of federal land, which could be used for a college campus or sold to provide funds to build a college. Originally vetoed by President Buchanan, it was signed into law by President Lincoln in 1862.[27]

The Morrill Act had a profound impact on higher education in the United States. More than 70 colleges and universities, developed with a strong focus on engineering and science, responded to the call to work with industry. In 1876, the founding of Johns Hopkins University represented another milestone. It was the first institution of higher learning in the United States to be based on the German research university, where discovery was primary and teaching undergraduates was secondary. While this model was never adopted in its most formal sense, it did encourage the development of research as a principal activity at major universities. In tandem, the land-grant movement and the research university concept molded the landscape for American universities. Over time, the differences between land-grant and research universities gradually lessened, and today hundreds of universities in the United States are active in research.

SETTING THE STAGE FOR SCIENTIFIC PREEMINENCE

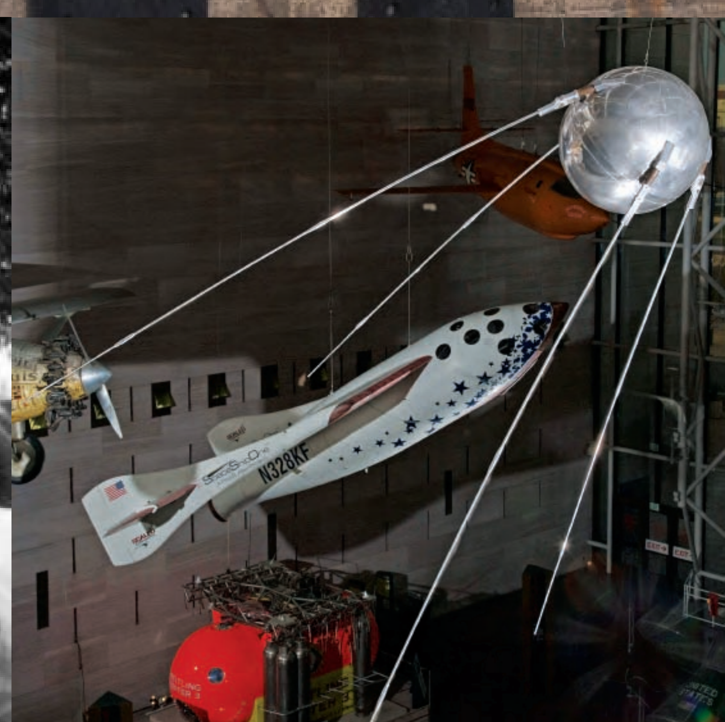
Another force for science and technology came in the 1800s, as the federal government began to recognize the need for and value of agencies that applied science. Government agencies began building their own research capabilities, while specific agencies formed around Earth and space science. The Coast Survey, formed in 1807, began formal mapping of the nation's Atlantic Coast. This effort became the U.S. Coast and Geodetic Survey in 1878, and is now part of the National Oceanic and Atmospheric Administration. In 1830, the Office of Standard Weights and Measures was formed, today known as the National Institute of Standards and Technology. After the Civil War, the U.S. Commission on Fish and Fisheries came into being with Spencer Baird, second secretary of the Smithsonian, as its first commissioner. It was followed by the U.S. Geological Survey in 1879.

From the first, America was led by men who believed in liberty and established one of the world's first democracies out of the crucible of war. They also believed in science and built the first institutions that brought it to the consciousness of the new nation's citizens. America's leaders espoused the concept of free inquiry, encouraged scientific exploration and discovery, and shared the findings with the nation's students and citizens. Jefferson saw this process as critical to educating a citizenry that would sustain the new republic.

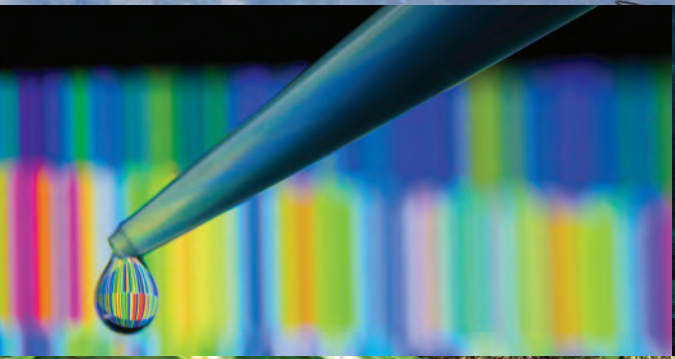
The work of the early scientists and the founding fathers encouraged creativity and boldness in the next generation of leaders, who created institutions such as the Smithsonian, land-grant universities, and key federal science agencies. These institutions accelerated the growth of the nation's capacity for science and technology, enabling the United States to catch up with Europe and laying the foundation for American scientific preeminence in the 20th century.

CHAPTER TWO

THE KNOWLEDGE EXPLOSION AND EMANCIPATION OF THE DISCIPLINES







CHAPTER TWO
THE KNOWLEDGE EXPLOSION AND EMANCIPATION OF THE DISCIPLINES

SCIENCE AND TECHNOLOGY continued to expand in the 20th century, but their growth was far from linear. Developments came in fits and starts in a century torn by two world wars, plagued by a decade-long depression, and roiled by social transformations. But it was also a century inspired by space exploration and galvanized by the power of a tiny device called a transistor and its offspring, computing and communications technology. Things got off to a fast start as new ideas and inventions derived from the work of 19th-century scientists and engineers came to fruition. Many were transformative, including radio (1901), the first mass-produced automobile (1901), air conditioning (1902), motorized airplanes (1903), and the Theory of Relativity (1905), while others were intensely practical, such as teabags (1904), Dixie Cups (1907), cellophane (1908), the modern zipper (1913), and the bra (1913).[1] The disposable Dixie Cup helped stop the spread of disease by replacing the common dipper in drinking barrels found in subways and roadside stops.[2]

The Depression and World Wars I and II slowed progress, yet each paved the way for the tremendous advancement of science and technology in the United States. World War I brought machine guns, tanks, airpower, and chemical warfare. Coinciding with the Great Depression, the Dust Bowl caused ecological damage and human displacement, making an urgent case for agricultural science that could lead to sustainable land use. During World War II, developments such as radar, encryption, and the ability to split the atom proved emphatically that science and technology were critical to victory.

While World War II disrupted millions of lives, out of the chaos came opportunity. Some of Europe's most brilliant scientists, including Albert Einstein and Enrico Fermi, emigrated to the United States before the war to escape oppression, and more scientists and engineers came at the war's end, including many who had worked for the German war machine. The GI Bill made it possible for thousands who might never have had an opportunity for higher education to attend colleges and universities, and many of those with a practical bent went into engineering.

Scientists and engineers whose pre-war careers were interrupted by the call to develop new military technologies sought ways to turn the technological advances of the war to civilian purposes when they resumed their university posts. Stanford University's Fred Terman, who led the effort to invent radar jammers during the war, helped to develop Silicon Valley;[3] and MIT's Vannevar Bush, the primary organizer of the Manhattan Project, promoted the idea of the National Science Foundation (NSF).[4] Upon its founding in 1950, the NSF provided U.S. research universities with a new source of funds for basic research in science and engineering. At the same time, the Defense Department began building its own capacity for research, based on the advances made during the war.

A NEW ERA OF TECHNOLOGICAL ADVANCEMENT

Even as this new infrastructure for the nation's research system was taking shape, a small silver ball called Sputnik was changing the playing field yet again. The Soviet Union's successful launch of *Sputnik 1* in 1957 caught the United States by surprise. The resulting reassessment of the nation's science and education enterprise led to the founding one year later of the National Aeronautics and Space Administration (NASA) and the Advanced Research Projects Agency (ARPA). Both entities had their own research capabilities and also provided substantial funding for external institutions, fueling further activity at the nation's research universities. Concurrently, Congress passed the National Defense Education Act of 1958, which provided funding for students who wished to major in science and engineering to attend universities of their choice.

THE SOVIET UNION'S SUCCESSFUL LAUNCH OF *SPUTNIK 1* IN 1957 CAUGHT THE UNITED STATES BY SURPRISE.

The stage was now set for a rapid increase in research and graduate programs in the sciences and engineering across the nation. And increase they did. In 1958, the federal government expended $7 billion on research and development while industry, a junior partner in the enterprise, came in at $3.7 billion. By 1985, the federal government's commitment had reached a remarkable $52.6 billion, a seven-fold increase from 1958. Industry, realizing the power of research and development to drive competitiveness, shed its status as junior partner and invested an impressive $58 billion in 1985, surpassing the federal government for the first time. It was no one-time fluke, but rather the passing of the baton to industry as the leading funder of research and development. Since 1985, the gap between industry and federal government in research expenditures has widened, with 2008 figures showing industry expenditures at $267.8 billion while those of the federal government were a mere $103.7 billion.[5]

INCREASED RESEARCH SPENDING, SCIENTIFIC SPECIALIZATION, AND GLOBALIZATION

Regardless of the source, spending on research and development increased dramatically during the second half of the 20th century, rapidly growing the sector from a cottage industry to big business. This trend did not escape the notice of aspiring university administrators, whose budgets were hampered by parsimonious state allocations or slowly rising endowments, and who saw research and development as a way to add value and relevance to their institutions. As the money rolled in, it is no coincidence that the number of students majoring in science and engineering also increased dramatically. Science and engineering degrees awarded by U.S. colleges and universities rose from 150,000 in 1958 to 421,000 in 1985, and then to 639,000 in 2008.[6] Not only did research funds support fellowships and assistantships for graduate students, but students also regarded funding trends as a bellwether of career opportunities. The jump in enrollment from 1985 to 2008 was heavily weighted toward medical and bio-related disciplines, due to a large infusion of research and development funds in these fields.

Coupled with the development of powerful research tools, rapid growth in research led to fields of endeavor that went beyond the conventional to form entirely new disciplines, such as computer science, informatics, artificial intelligence, neural networks, nanotechnology, and supramolecular chemistry, just to name a few. Existing disciplines were combined in new ways, resulting in fields such as bioinformatics, nanotribology, digital media, biological engineering, and paleoseismology. These new fields added to rather than replaced conventional disciplines. As the 20th century drew to a close, universities found they were riding a tiger, struggling to meet the demand for additional faculty and new laboratory space and equipment, which strained both their finances and their organizational structures. These issues remain a challenge into the 21st century.

America's success in using research and development to power its economy did not go unnoticed around the world. Initially, developed nations such as those of continental Europe, Great Britain, and Japan joined the race, followed by emerging Asian economies including Singapore, South Korea, and Taiwan. More recently, China and India have joined the fray along with oil-rich Arab nations. By 2007, the NSF estimated that annual worldwide research and development expenditures totaled more than $1.1 trillion, with a third of that in the United States. Europe accounted for almost a quarter of it, and Japan about 13 percent. Although China was responsible for just nine percent of the total expenditure, its investment in research and development has grown rapidly over the past decade, averaging a 19-percent annual increase compared to 3.3 percent for both the United States and Europe.[7] Each player in this global research enterprise is focused on the same thing: winning the hearts and minds of the world's brightest researchers and scholars and supporting them as they develop the next printed circuit, cure for cancer, or other innovation that will help to drive a nation's economy forward in today's technology-based global marketplace.

Adding fuel to the information/knowledge explosion generated by an expanding research enterprise was the rapid growth of computing power and digital networks. The invention of the transistor in 1948 by William Shockley of Bell Labs,[8] and then of the integrated circuit in 1958 by Jack Kilby of Texas Instruments,[9] triggered a wave of ever-expanding technological revolutions that we are still riding today. In 1965, Gordon Moore, co-founder of digital giant Intel, predicted that the number of transistors on a chip would double every two years, effectively providing a tenfold increase in power with each doubling.[10] This pattern, known as Moore's law, has held so consistently through the intervening decades that it is used by the semiconductor industry as a guide for long-term planning.

A TORRENT OF INFORMATION

An expanded research enterprise has unleashed an epochal flood of information.

- The 2010 IDC Digital Universe Study projected that during 2010, humankind would generate 1,200 exabytes (each exabyte equaling one billion gigabytes) of data,[11] and the U.S. Council on Competitiveness estimated that 40 exabytes of that total will be new and unique — more than all of the new information generated in the previous 5,000 years.[12]
- The Internet, the ancestor of which was created in the early 1970s by ARPA to allow researchers to communicate effectively, changed the world when the World Wide Web became available for public use in the early '90s. Radio took 38 years to reach 50 million users; Facebook got there in a single year.[13]
- Skype, which began offering computer-to-computer audio and video calls in 2003, had 443 million users by the first quarter of 2009.[14]
- Steve Jobs announced in January 2010 that in the preceding eighteen months, users of Apple's iPhone had downloaded 3 billion applications, with one third of those downloads occurring within the last three months of 2009.[15]

No part of the world remains unchanged by the information revolution, and the power of the technology continues to expand as electronic communication merges with computing in new and creative forms.

RAPID SPECIALIZATION NARROWS FIELDS OF STUDY

An inadvertent consequence of the rapid expansion of research and development and the resulting information explosion has been the specialization of science and engineering. In a somewhat perverse application of the principle of conservation of mass, which states that the mass of a closed system will remain constant, the growth in specialization has been accompanied by shrinkage in the area any given specialty covers. In essence, the more disciplines there are, the smaller the knowledge base each one addresses. About.com's list of scientific "ologies" now numbers 162 and is still growing.[16] Some are familiar to the average person — biology, ecology, geology, radiology, and zoology, for example — but most will elude all but a rarified few experts. The list begins with acarology (the study of ticks and mites), passes along through coleopterology (the study of beetles), edaphology (the study of the influence of soil on life), kymatology (the study of wave motion), oology (the study of eggs), and xenobiology (the study of non-terrestrial life), then closes with zymology (the study of fermentation). Interestingly, the "ologies" themselves are apparently not comprehensive enough, resulting in the launch of sub "ologies" such as paleolimnology, paleoecology, and paleoseismology, not to be outdone by molecular biology, cellular biology, systems biology, synthetic biology, marine biology, population biology, and pathobiology.

Of course, a list of "ologies" is not a comprehensive representation of the sciences since it does not even touch additional primary disciplines such as chemistry, physics, and mathematics, each of which has upwards of 20 to 30 subfields. Then there is engineering, which includes another 120 disciplines and sub-disciplines. Today, there are more than 300 fields of study in science and engineering, up from zero at the beginning of the Age of Enlightenment — a case of intellectual evolution run riot. Using Darwin as a guide, the Clough theory of disciplinary evolution states that "a specialization will evolve to fill a niche of knowledge, no matter how small." If there is merit in this analogy, what happens when we add the Darwinian corollary that if a species overspecializes, it risks extinction as conditions change? Is there enough bamboo to feed all of those disciplinary pandas we have created?

We are centuries past the time when one person could learn all, or even most, of what there was to know. Someone out there may be an expert in both acarology and zymology, but I have yet to meet this person. One has to look back to the Age of Enlightenment to find people who purportedly were masters of knowledge that spanned from arts to sciences. Johann Wolfgang von Goethe (1749–1832) has been characterized as the last person to know it all and Alexander Von Humbolt (1769–1859) as the last "universal man." Instead of "universal" people who can see the big picture, we now have a teeming sea of experts who know more and more about less and less, even as we are confronted by a knowledge and information base whose exponential expansion rate exceeds our ability to process it. And there is no end in sight. New tools of discovery are continually being created — from giant telescopes that can see through clouds and across time to computers whose processing power outstrips that of the human brain — and the number of researchers using such tools is increasing. If anything, knowledge will continue to grow at an accelerating pace.

SCIENCE AND TECHNOLOGY IMPROVE THE QUALITY OF LIFE

Despite their complications, there is no doubt that the development of science and technology has produced an astounding array of benefits for society. Economic productivity and quality of life improved over the past 100 years, and we have seen life expectancy for most of the world increase by more than two decades, to an average lifespan unheard of in the past. We travel thousands of miles in mere hours on journeys that a century ago would have taken weeks. Air conditioning has made work in hot climates as convenient and productive as in cooler ones, which I can appreciate, having grown up in southern Georgia before this wonder was available to the average person.

My personal perspective on the advances of the past century comes from the dramatic impact of science and technology on the lives of my own parents. They were born in 1902 on nearby farms in the rural Deep South, and they were actually better off than many of their neighbors, especially those who worked on tenant farms. Each of my parents had ten brothers and sisters. Lack of access to medical care and limited knowledge meant that several of their siblings died in childhood from diseases now vanquished or curable. There were no paved roads or home-based communication systems; water was drawn with buckets from outside wells; the bathroom was an outhouse; and the house was lit with oil lamps, not electric lights.

My own childhood with my parents in a modest home in the town of Douglas, Georgia, included more conveniences; but when I visited my grandparents in the country, life was much the same as it had been for my parents when they were growing up. I watched the women of the family fire up wood stoves and cook meals from home-grown vegetables and meats. There was a beauty in this life, and I have nostalgic memories of lounging in a front porch swing on hot summer days, shaded by mimosa trees with their exotic, bright pink-and-white blossoms. But it was a life of hard work with little time to expand a child's horizons, limited opportunities for education and health care, and few connections with the larger world.

Today, advanced logistical systems ensure that even in rural America, grocery stores carry a rich array of foods produced by an agricultural enterprise that is remarkably efficient and automated. With the advent of automatic washers, dishwashers, vacuum cleaners, self-regulating ovens, and electronic appliances, household chores are no longer numbingly difficult. The large majority of families have automobiles for personal transportation, and these are vastly safer and more reliable than those of even a generation ago. Entertainment is available on demand, and instant communication is no longer the exclusive purview of the land-line telephone. Mobile devices allow us to connect with anyone at any time and put a world of information at our fingertips besides.

Beyond our homes, massive road networks now span our nation, and clean water and sanitation systems serve our cities and towns. Power plants and grids provide reliable electricity to heat and light our homes. Every child has access to at least a basic education, and an unparalleled system of colleges and universities provides opportunities for higher education. Our armed forces can defend us against almost any threat with far fewer soldiers than were required in the past. Today's scientific instruments allow us to peer into the deepest realms of space as well as manipulate atomic structures at the nanoscale to create new materials and develop new tools to fight diseases that have plagued our species throughout history. Robots assist in the manufacture of remarkably reliable automobiles, help surgeons operate on a beating heart, and tackle the most dangerous tasks of disaster response, rescue, and warfare. Computational power is growing at a dizzying pace. Decoding a person's genome, which involves analyzing three billion base pairs of DNA, took ten years the first time it was done in 2003. It can now be completed in a week. Similarly, the Sloan Digital Sky Survey, which opened in New Mexico in 2000, gathered some 140 terabytes (one terabyte equals one trillion bytes) of data during its first decade of operation; the Large Synoptic Survey Telescope, scheduled to come on-line in 2016 in Chile, will gather that much data every five days.[17]

RAPID ADVANCES LEAD TO KNOWLEDGE GAP

Our science and technology enterprise is the envy of the world, and the vast majority of Americans believe that science has made their lives better. Yet there is also cause for concern. Society takes the benefits of science and technology largely for granted, and we are losing our ability to understand how things work. Trust in science is declining, as are the test scores of U.S. students. Every three years, the Program for International Student Assessment test is given to 15-year-olds in member nations of the Organization for Economic Cooperation and Development, which includes the world's 30 wealthiest nations. The test measures the students' ability to apply math and science knowledge in real-life contexts. In 2006, the United States placed 17th among the 30 nations, its students scoring just 489 of 1,000 possible points — 11 points below the average of all 30 countries.[18]

In a world dominated by technology and facing major environmental problems, an understanding of the basic principles of science is a necessity. Yet NSF surveys find that most Americans do not have a good grasp of basic science knowledge and do not understand the process of scientific inquiry. The same surveys indicate that Americans show less interest in following science news and developments than do citizens of Europe, China, and South Korea.[19]

AMERICANS AND SCIENTIFIC LITERACY

- A 2009 national survey by the California Academy of Sciences indicated that only 59 percent of adults knew that early humans and dinosaurs did not coexist; only 53 percent knew how long it takes the Earth to orbit the sun; only 47 percent could give a rough approximation of how much of the Earth's surface is covered with water; and only 21 percent knew all three of these things.[20]
- Fresh water is likely to become one of the world's most pressing environmental issues in the future, yet fewer than one percent of American adults know what percentage of the planet's water is fresh as opposed to salt.[21]
- According to Michigan State University Professor Jon Miller, who has been measuring scientific literacy in the United States and around the world for the past 30 years, only 28 percent of Americans are scientifically literate, which he defines as able to understand most of the scientific concepts and terms presented in the Public Broadcasting Service show "NOVA" or the science section of *The New York Times*.[22]

In its early days, science was much more accessible to ordinary citizens. Early scientists used familiar and commonly available materials and tools, and for the most part, did their work in plain view of the general public. Benjamin Franklin, for example, conducted his experiments in his house and in nearby fields, and neighbors constantly knocked on his door wanting to watch.[23] As the body of scientific knowledge expanded and its concepts grew more complex and esoteric, the work of science gradually retreated into laboratories fitted with highly specialized equipment. The more specialized and sophisticated science has grown, the more difficult it has become for ordinary citizens to understand its workings and its outcomes.

Today's dizzying array of specializations and their arcane, hierarchical vocabularies make it impossible for a layperson, no matter how interested, to understand what is going on. In addition, despite receiving a significant portion of their research funding from the taxpayers, scientists don't seem to care about communicating with the public about their work. Indeed, the arrogant and dismissive attitude of some scientists compounds the problem.

SCIENCE GOES ON TRIAL

Depending on your point of view, science and religion are integral and complementary, or are separate and sometimes in conflict. The latter school of thought is a self-fulfilling prophecy when a religious adherent interprets the Bible literally in the face of the ever-expanding findings of science. In the seventeenth century, Galileo Galilei spent the last ten years of his life under house arrest because his telescopic confirmation that the Earth rotated around the sun was said by the Catholic Church to be "false and contrary to the Scripture."[24] It took many years for the Church to admit its error. In the nineteenth century Charles Darwin, a devout Christian, knew his concepts about evolution would bring him into conflict with some church authorities.[25] He was not wrong; to this day the issue remains a point of controversy. It boiled over in the United States in 1925 when the right of John Scopes to teach evolution in a public school was put on trial in Dayton, Tennessee.

While textbooks in Tennessee in 1925 covered the topic of evolution, Tennessee's Butler Act made it illegal for any teacher at a public educational institution in that state "to teach any theory that denies the Story of the Divine Creation of man as taught in the Bible, and to teach instead that man has descended from a lower order of animals."[26] John Scopes agreed to test the law by using the textbook lessons about evolution in his class. The case became a cause célèbre as famous lawyer and declared agnostic Clarence Darrow joined the defense team and William Jennings Bryan, a perennial presidential candidate, avowed Christian, and opponent of evolution, joined the prosecution. The trial resembled a sideshow as it attracted a host of reporters from newspapers and the new medium of radio, along with religious groups who marched through the town condemning the teaching of evolution and conducting mass baptisms.

Defense lawyers planned to base their argument on the First Amendment to the Constitution, contending that Scopes' right to free speech was being abridged by the Butler Act. They invited a number of well-known scientists to testify on behalf of the defense in support of the evidence for evolution. Many of the scientists were confirmed Christians who also believed strongly in evolution. However, the trial judge, John Raulston, limited the scope of the trial and only one of the witnesses was allowed to testify. Others were allowed to submit written testimony that was not used in the trial but was to be available in the case of an appeal. The Smithsonian itself participated by submitting written testimony.

In the end the defense focused on an approach that attempted to show that the Biblical creation story should not be accepted literally because scientific findings showed otherwise. Darrow even called Bryan as a witness and was able to get Bryan to contradict himself as he attempted to reconcile the creation stories in the Bible with the findings of science. The trial was good theater, but it did not lead to the correct test in the context of the First Amendment. In the end, John Scopes was fined $100, which was paid for him by a newspaper. It was not until 1967 that the Butler Act was finally repealed after other lawsuits settled the issue on the right to teach evolution as a First Amendment right.[27]

Beyond the legal proceedings at the Scopes Trial, the media took sides depending on political leanings and the region of the country they represented. Words piled on words and heightened tensions between those who felt evolution threatened their religious beliefs and those who felt that science had duly proven the concepts of evolution. The words were often not kind. Covering the Scopes trial for the *Baltimore Evening Sun,* H.L. Mencken wrote, "The so-called religious organizations which now lead the war against the teaching of evolution are nothing more, at bottom, than conspiracies of the inferior man against his betters."[28]

These comments and others like them created an antagonism that never went away. Ridiculing those who disagree based on their religious beliefs may give some people a sense of self-satisfaction, but it undermines our collective ability to reason together and improve scientific literacy. I was raised in a small town in southern Georgia. Many good people who lived there, including my parents, likely did not understand evolution. My parents grew up in difficult times in the Deep South, where educational opportunity was limited for whites and blacks alike. They were denied the chance to attend a university, but at every turn they focused on creating an opportunity for their children to get the education they had missed. They were tolerant people, and my father often told me to respect every person because I would learn something from them if I listened. I learned early that characterizing a broad class of people as "inferior" and less than their "betters" is not useful and widens, rather than narrows, the gap between them.

EVOLUTION IS A SCIENTIFIC REALITY THAT MUST BE TAUGHT IN OUR SCHOOLS, AND OUR CHILDREN HAVE TO UNDERSTAND IT IF THEY ARE TO BE SCIENTIFICALLY LITERATE.

DIFFERENT ROLES FOR SCIENCE AND RELIGION

At the first Republican presidential debate prior to the 2008 election, the candidates were asked if they believed in evolution.[29] Three indicated that they did not, and the academic and elite Greek chorus clucked in a self-satisfied way. Yet the real issue is not whether these candidates believe in evolution, but whether they believe in the founding principles of our nation. Among these are the First Amendment guarantee of free speech, and the separation of church and state in the matter of public institutions. Accepting these fundamentals is a first step to clarifying how science is taught in public schools and universities.

Evolution is a scientific principle that has been extensively tested and consistently found to work, regardless of the environment. I have been in Antarctic valleys where it has not rained for more than two million years, yet creatures have evolved over time to survive in even these extreme conditions. Evolution explains how life adapts for survival in ecosystems where conditions vary and change constantly. Evolution is a scientific reality that must be taught in our schools, and our children have to understand it if they are to be scientifically literate. In contrast, religious beliefs cannot be tested objectively. But they help establish our moral order, provide the basis for understanding why we are here, and give meaning to our short lives and ultimately to our deaths. Our founding fathers understood that forcing people to accept a religious doctrine in which they do not believe, or positing and teaching religion as science, is essentially advocating a state religion.

The role of the First Amendment and the concept of separation of church and state are an integral part of this dialog in which Americans attempt to find common ground on matters of science and religion. It seems this common ground must be earned generation by generation, but the effort involved in finding it and in expanding the understanding of the context for science and religion is worth it.

The National Museum of Natural History at the Smithsonian provides an example of an educational resource that respects the integrity of religious perspectives while laying out the facts of evolution as applied to our own species. The Smithsonian has conducted research on human origins in Africa and Asia for more than a century, and its findings have contributed to a better understanding of the earliest humans and how they interacted with their environment. This work, added to that of others in the field, has now reached a maturity that allows a much-improved understanding of how humans evolved.

In the Natural History Museum's new Hall of Human Origins, scientific evidence and skeletal remains of early human species reaching back six million years are convincingly displayed so that the seven-million-plus visitors of all ages who come to the museum each year can see what we know. This growing body of information, representing the work of hundreds of paleoanthropologists and other scientists, states a profound case, not only for the evolution of humans, but also for the steady extinction of earlier human species, with only our own, *Homo sapiens,* remaining. In its conclusion, the exhibit pointedly says that *Homo sapiens* is a relatively new species, probably about 200,000 years old, whose future depends increasingly on an understanding of the natural world and the choices that must be made about it.

The exhibition represents a new approach, offering an interactive learning experience that is welcoming to people from a wide variety of perspectives. It begins with humor, pointing out that we share 60 percent of our DNA with a banana. Moving up the scale, we share 85 percent of our DNA with a mouse, and the connection grows ever stronger as we move closer to our own evolutionary lineage. Life really does have a common basis, and humans are part of it in the larger scheme of things.

To bring an awareness of religious perspectives to bear on the subject of human origins, an advisory group was formed. The Broader Social Impacts Committee, composed of representatives from a wide variety of religious traditions, helped develop the exhibition script and outreach materials with an eye toward encouraging respectful dialog, and committee members continue to participate in public forums designed to promote constructive relationships among those who have differing perspectives. Additionally, the exhibition features a digital forum where visitors can express their opinions about what they see. The intent of the exhibition is to use scientific findings to educate all who come to see it and/or visit its website. Its approach not only acknowledges that people with differing points of view will need to reconcile what they see with their own belief systems, but also admits that the science of human origins is far from finished and will continue to be modified as scientists learn more. The exhibit allows for new findings to be accommodated as they occur.

GROWING DISTRUST OF SCIENCE

The decline of scientific literacy leads to a growing distrust of science and scientists, and with it a decline in public support for scientific discovery. Exhibit A is the recent supercharged rhetoric and mixed messages about climate change. We know that climate change has been occurring for a very long time — long before *Homo sapiens* was on Earth. Many different mechanisms provoke climate change; some are cyclical, such as the gradual change in exposure of the Earth to the sun as a result of the tilt of its axis, while others are episodic, such as large volcanic eruptions. The geologic record documents large, prolonged changes in climate; one such is termed the Paleocene-Eocene Thermal Maximum (PETM), a period of significant global warming that occurred 55 million years ago. Smithsonian paleobotanist Scott Wing discovered rock exposures in the Bighorn Basin of Wyoming dating back to this period, and decades of digging have uncovered fossils that demonstrate the extensive warming the planet experienced. By collaborating with colleagues from other specialties, Wing has been able to describe what it was like for the mammals, fish, and plants of the time. As temperatures rose, Wyoming's climate became much like that of northern Mexico or parts of southern Georgia and Florida today.[30]

When the work of Wing and his team is combined with that of scientists who study cores drilled from the ocean floor that show sweeping patterns of climate change stretching back millions of years, the PETM emerges as a world where polar ice melted, sea levels rose by as much as 300 feet above those of today, the ocean acidified, and life often lost the struggle to adapt.

Many of the findings about the PETM are well established and make clear that large-scale warming would be devastating to life as we know it. It is all the more important given that in the past 100,000 years, our species has expanded from a mere handful to seven billion today and is expected to increase to more than nine billion by 2050.[31] While human beings did not exist during the PETM, we now have become a documented agent of change. We generate substantial amounts of greenhouse gases and cut down large areas of forest that would otherwise help absorb them. Scientists are nearly unanimous in their expectation that such activities will have an impact on our future, though they do not know exactly how the different natural elements involved in climate change will interact with each other or precisely what role our own activities will play in those interactions. Scientists have gained much knowledge and insight into climate change, but we still have much to learn. Admitting we do not know it all is hard for some to do, and there are those who would use such an admission to advocate that we should do nothing. Still, the case must be presented on its merits and the debate engaged on the appropriate terms.

Recent surveys show that while a majority of Americans believe global warming is occurring, their belief is currently based on immediate impressions rather than a grasp of basic science. A January 2010 survey by Yale and George Mason Universities shortly after the release of controversial e-mails by climate scientists showed a significant drop from a year earlier in the number of American adults who believed global warming was happening and who trusted scientists as a source of information about it.[32] By the time of a parallel June survey, the numbers had begun to rebound — according to Anthony Leiserowitz of Yale, a reflection of the waning of "climate-gate" from the daily news, as well as other factors such as an improving economy and the BP oil spill in the Gulf of Mexico, which called attention to the dark side of reliance on fossil fuels.[33] If we are to garner the consistent public support that will be needed for the long-term response that climate change requires, we need to find ways to clearly communicate what we know and do not know.

Ironically, even as we continue to struggle with what are often abstract debates about the causes of climate change, it is beginning to have a very real impact. I recently traveled to Alaska to open a new exhibit, "Living Our Cultures, Sharing Our Heritage: The First Peoples of Alaska," at our National Museum of Natural History's Arctic Studies Center at the Anchorage Museum of History and Art. While in Alaska, I traveled with two Smithsonian scientists to the Yupik village of Gambell, located on St. Lawrence Island in the Bering Strait. St. Lawrence Island is a low-lying land mass formed from volcanic rock and accumulated deposits of sand and gravel on the coasts. The day we arrived it snowed and small icebergs floated in the sea. It seemed an odd place to talk about global warming.

The Yupik are an ancient people who have survived for thousands of years as subsistence hunters, using the land, ice, and sea to hunt whales, walrus, fish, and waterfowl. At the local high school we met with the village elders, men who for a lifetime have hunted from small open boats in the face of one of the most hostile climates in the world. Evidence of the year's hunt was on the beach in the form of the bones of five whales killed recently. While the whale hunt had been good, it did not take long for climate change to come up, and once mentioned, each of the elders had a story to tell. The ramifications are multifold. Permafrost is melting, weakening the bottom of the island lakes and allowing the water to drain. Ducks and geese no longer land there. The sea ice is no longer thick enough for the walrus to haul out close to the island, and the boats cannot be relied upon to reach the thicker ice far to the north. The warming seas spawn summer storms that erode the land, undermining the foundations of buildings, and prevent hunters from hunting. For the first time in anyone's memory, sub-arctic sharks have been seen on the hunts. The elders are concerned for their children and grandchildren and their future. At the conclusion of the discussion, they asked us why more people are not worried about the very real changes they see day to day. Good question.

Farther south, the citizens of New Orleans also have reasons to be concerned about climate change. With much of the city lying below sea level, the levees and flood walls surrounding it are crucial to warding off the effects of storm surges from hurricanes. Hurricane Katrina was a wake-up call in more ways than the obvious damage that citizens around the world saw during the event itself. In the aftermath of the hurricane, I was asked to chair the National Academies Committee on Hurricane Protection for New Orleans to provide oversight for the reconstruction of the hurricane protection system. Early on in our work, we came face to face with an issue related to global warming.

One of the first actions undertaken after the disaster was to measure the height of the levees that remained. This task proved to be problematic, because the original elevations set for the levees were based on sea level. But sea level is not the constant it once was perceived to be. Because of global warming, sea level has been rising for about the last century at a rate of two to three millimeters per year. Over a century, the rise in sea level amounts to between 0.7 and 1.0 feet. Although few of the levees had been around for a century, the effective height of all the levees in terms of flood protection was less than believed because the level of the waters of the Gulf had risen over time.

This reality was food for thought in itself, but it became a critical issue in the design of the reconstructed flood protection system. Looking ahead, the levees should ideally provide protection for a long time — one century or more — and prudent design should take into account sea-level rise over that time. How much higher should the levees be built to accommodate rising sea levels? This question is not easy to answer, because recent evidence points to an acceleration of the rate of sea-level rise. Designers could easily justify projecting two to three feet in sea-level rise, causing a significant increase in the required height and size of the levees. The choice is not an abstract one; it is a matter of the potential for enormous property damage and loss of life. It is a matter that threatens the future of one of America's great cities.

Whether you live in the far north of our nation on St. Lawrence Island or the far south in New Orleans, the impact of climate change is very real. Both of these locations are seeing harbingers of the future, a future that will require us to make critical decisions. If we are to provide future generations with a chance to meet the challenges they will face, we have to understand and appreciate the science behind climate change.

Is our situation hopeless? Those charged with helping the public understand science and technology struggle in light of an accelerating knowledge base and ever-increasing specialization. It is time to sort out the real issues from the false, to work on reducing the unneeded complexity that surrounds science, and to seek common ground, as Harvard's E.O. Wilson makes clear in his book, *The Creation: An Appeal to Save Life on Earth.*[34] Arrogance has no place here; too much is at stake. Such attitudes are a threat to the vitality of science and technology and hence our ability to sustain our standard of living. In the next chapter, I will suggest a few ideas that I believe can help increase scientific literacy.

CHAPTER THREE
RIGHTS AND RESPONSIBILITIES


CIT
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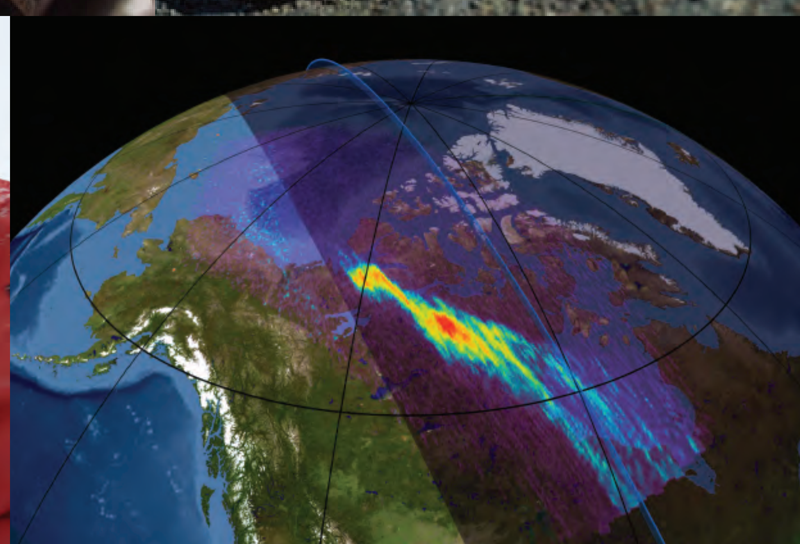

CHAPTER THREE
RIGHTS AND RESPONSIBILITIES

CHANGING TIMES PRESENT us with a conundrum. Today, science and technology form a global enterprise fueled by billions of dollars from governments and industry and driven by a growing army of researchers. Our ability to survive as a society depends in large part on the innovations brought about by scientists and engineers, whose past work has dramatically improved everyday life in most of the developed world. And yet the public is growing uneasy about the same enterprise from which it benefits so greatly. The sheer volume of scientific knowledge has triggered the viral growth of specialization, dividing that knowledge into smaller and smaller pieces understood by fewer and fewer people. With communications moving at warp speed and computing power reaching mind-boggling proportions, the pace of technological advancement threatens to overwhelm us. National Science Foundation surveys indicate that while the vast majority of Americans are positive about the contributions of science and technology to their lives, nearly half have grown concerned about how fast things are changing.[1]

Who is going to help the general public understand the onslaught of new developments that are coming? Who is willing, or able, to vet potential negative consequences? We need a game plan for responding to this dilemma. Instead, we are buffeted by advocacy groups, some of which express unchecked optimism, while others call for a halt to progress in the name of the environment. Both sides exhibit a fragmentary understanding of science. Absolutism can lead to disillusionment, as was demonstrated by the 2009 Copenhagen summit on climate change, at which developing countries rebuffed calls for sacrifice. Environmentalists from developed countries, which had long ago cut down their forests and rapaciously used their natural resources, were now asking others to "do the right thing." Their arguments fell on deaf ears. In the end, the summit attained a modest agreement, but it will have little impact on the issues we need to address.[2] This unsatisfactory experience reinforces the need for a broader appreciation of the science underlying the challenges and opportunities we face. Without it, common ground is difficult to find.

WHO IS GOING TO HELP THE GENERAL PUBLIC UNDERSTAND THE ONSLAUGHT OF NEW DEVELOPMENTS THAT ARE COMING?

UNDERSTANDING THE CONSEQUENCES OF SCIENCE

Science and technology are in themselves neutral. While they have enormous benefits when used advantageously, we must also anticipate, and develop strategies to mitigate, potential negative effects.

The splitting of the atom was one of the great scientific accomplishments of the 1930s and '40s. Its first application took the form of the atomic bomb. Before the world could realize the peaceful use of nuclear power, we witnessed the immense devastation it could cause. The vivid images from Hiroshima and Nagasaki triggered a fear of nuclear weapons that continues to this day, exacerbated by the nightmare of what could happen if such weapons fell into the hands of a rogue nation or terrorist group.

Other menaces sneak up on us more quietly, and their effects are more difficult to portray. Take the growing accumulation of plastic in our land and oceans. Invented about the same time as nuclear weapons, plastic has become ubiquitous and its deleterious effects have accumulated slowly. A look around our disposable society reveals a plethora of plastic: wraps, bags, containers, water bottles, equipment parts, printer and telephone housings, plumbing pipes, pens, electrical outlets, prophylactics, stems for cotton swabs, and parts for automobiles and airplanes, just to name a few. But plastic also has found its way — in exponentially increasing amounts — into our planet's land and water, and even into the food we eat, in the form of microscopic pellets ingested by the creatures in our food supply.[3] On a recent trip to Alaska I flew in a floatplane to the remote and beautiful Northwestern Fjord on the Kenai Peninsula. As we visited sites of former habitations by ancient peoples, I looked along the beach and saw plastic bottles, floats and containers littering this pristine place. We worry about nuclear waste, which has a dependable half-life, but most of us are unconcerned about plastic waste, which is here to stay and does not biodegrade.

The potential of plastic in the environment to do us harm should be cause for serious trepidation. To their credit, a number of scientists and concerned citizens are raising their voices in alarm, but the public has not yet heard them. Periodically, a sad picture of a waterfowl with its neck caught in a noose of plastic netting arouses our sympathy, but the image does not result in a huge public outcry.

HUMAN ACTIVITIES THREATEN THE NATURAL WORLD

Of course, plastics are not the only substances with negative consequences that we humans are slowly adding to our environment. Another frequently discussed substance is carbon dioxide. Without question, humans are responsible for the increasing quantities of carbon dioxide in our atmosphere, generated principally from burning carbon-based fuels such as coal, oil, and gasoline. The debate simmers around whether this human-generated carbon dioxide can or will overpower and dominate natural climate processes. This debate has become polarized and taken on the cloak of religiosity in its intensity. Little room is left for concerned men and women who want to think through the options of what we should do in a realistic and pragmatic way. The focus on carbon dioxide also overshadows the reality that we are adding other harmful greenhouse gases to our environment, such as methane and sulfur dioxide. Everyone who cares about generations to come should be greatly concerned about the dangerous consequences of this continuing accumulation of gases in our atmosphere. Doing nothing or waiting to see what might happen next is neither an acceptable nor an intelligent option.

Beyond plastic and greenhouse gases, the list of harmful things we are slowly adding to our natural world includes hormones, antibiotics, livestock, and heavy metals. Hormones and antibiotics show up in the environment from medications that are flushed down toilets and from the waste of livestock treated to ward off disease or stimulate growth. These substances are wreaking havoc on the reproduction and health of fish and other creatures. Since humans are part of the chain of life, we can include ourselves as one of the species being affected.[4] The explosive growth in the demand for meat in the world's diet has caused the United Nations to identify livestock production as one of the three most significant causes of environmental problems. Livestock not only occupy a fourth of the world's land area and eat a third of its grain, but also produce 18 percent of the world's anthropogenic greenhouse gas emissions, including 37 percent of methane emissions and 65 percent of nitrous oxide emissions.[5] In another example, manufacturing processes for many of life's essentials produce byproducts which include heavy metals. Their potential to do us harm is growing as they accumulate in soils and are transported around the world by winds.[6]

Equally as threatening as slow additive processes are slow subtractive processes: the cutting of vast tracts of forests, destruction of wildlife habitat, depletion of biodiversity, melting of glaciers, and loss of topsoil. Despite the difficulty of seeing the end points of such slow developments, there are periodic bright-lines, such as the extinction of the passenger pigeon. In the 1800s, flocks of this beautiful bird, numbering in the billions, were said to blacken the sky for hours when they moved over the United States. Hunters thought nothing of slaughtering them, and then the clearing of the forests that formed their habitat brought them to an abrupt end. The Smithsonian is one of the few places where you can still see a specimen. When the last passenger pigeon, named Martha, died at age 29 at the Cincinnati Zoo, she was given to the Smithsonian to be mounted. I have seen Martha; her death is a haunting lesson.

But passenger pigeons are not the only species now extinct or headed for extinction as a result of human activity. One of the most prominent endangered species may be our own. This possibility comes through clearly at the National Museum of Natural History's new Hall of Human Origins, where visitors can view skeletal remains of dozens of lines of human species that arose over the last six million years. *Homo erectus* was the longest lasting, having lived for an estimated 1.8 million years before going extinct. The causes of extinction vary, but important factors include some still with us today, such as environmental degradation and climate change. *Homo sapiens* is both the latest and the only remaining species of the human family tree, and our time on Earth — about 200,000 years — has been relatively short. The lessons we learn from other species can help us extend our stay if we are wise enough to pay attention.

Science-based techniques have long helped the Smithsonian support the survival of endangered animal species, beginning with an effort in the early 1900s to breed and re-establish the American bison in the wild. The Institution continues these efforts through the Smithsonian Conservation Biology Institute at Front Royal, Virginia. Animals that once dominated the wild are rapidly losing the battle to survive as their habitat diminishes, migratory routes are cut off, and livestock overgrazing stresses wide areas, rivers, and streams. Over the past century, wild populations of the magnificent tiger dwindled from 100,000 individuals to fewer than 3,500, and three of eight tiger species are now extinct. In a partnership with the World Bank, the Smithsonian's National Zoo and Conservation Biology Institute are collaborating to help the 12 tiger-range countries train people in the techniques needed to protect the remaining wild tiger populations.[7] The number of endangered species should trouble us more than it does, since extensive diversity of species is essential to a healthy environment.

We have a responsibility to notice — and think seriously about — slow and incremental processes that add negative things and subtract positive things from the natural world. We must understand our environment before making changes, some irrevocable, that future generations will inherit.

BALANCING RIGHTS AND RESPONSIBILITIES

Throughout my professional life, I have had the wonderful opportunity to learn from a number of wise people, one of whom was Roberto Goizueta, former CEO of The Coca-Cola Company. An engineer by training, he had a pragmatic way of looking at things. He was a generous man, always willing to listen to new ideas. But when he heard ideas with no basis in logic, he would say, "Hope is not a strategy." I echo these words to all those who want to delay efforts to mitigate the many negative factors looming over our future: Hope is not a strategy. Nor is using ideology to justify ignoring these problems. We must do all we can while we can to avoid the day of reckoning, when it will otherwise be said of us that we had a chance to make a difference and failed to do our part.

The ultimate question is, what can we do? I believe that a big part of the solution comes down to scientific literacy — a term I use to cover both science and engineering. In the face of the tidal wave of knowledge and discovery that is coming at us, it is time for a new Age of Enlightenment. We must bring science and its future directions more fully into the public conversation if we as a society are to make wise decisions about our future quality of life and even our survival as a species. The more Americans know and understand, the less likely we are to be surprised by unintended negative consequences of our scientific advances.

There are reasons to be optimistic that we can do something about what seems an intractable problem. We can begin by using the very technology that confronts us with ever-increasing amounts of information as a tool for creating new ways of communicating and avenues for learning. We all understand that young people today learn and communicate in different ways from adults. This spectacular change has occurred in a very short time, in part because the technology is so robust. Science educators have yet to catch up with its possibilities. Their efforts must reach beyond illustrating lectures with computer graphics to employing digital communications to engage and inspire students with interactive and personalized activities. The end result should encourage ongoing activities that promote experiential learning for individuals and groups. If science educators are willing to work in concert with lifelong learning organizations and our K–12 schools to use digital technology in creative ways, the possibilities are endless.

Much is possible if we work together. Doing so requires us to hold conversations at many levels; encourage the active participation of scientists, parents, the media, and a variety of institutions; and agree how each entity can reinforce the efforts of the others. Thinking in terms of rights and responsibilities provides a context for the necessary course of action.

Parents: Allies in Improving Scientific Literacy

We can begin with parents. As President Obama pointed out in a July 2010 speech on federal education reforms, "We also know that as significant as these reforms are, there's going to be one more ingredient to really make a difference: parents are going to have to get more involved in their children's education."[8] Backed by our Constitution, parents have the right to teach their children whatever form of religious belief or doctrine they choose. But parents who care about their children's future will also ensure their education in science, because this world, and particularly the United States and our standard of living, depend on its findings.

To carry out their responsibilities, parents must be able to distinguish between science and religion and explain the difference. Albert Einstein, whose scientific research resulted in a deep conviction that the marvelous structure of the natural world was the work of an infinitely superior, wise, and radiantly beautiful spirit, had his own explanation. Science, he said, is a systematic, factual approach to discovering and understanding the perceptible phenomena of the natural world, whereas religious faith focuses on lifting humans above selfish baseness toward lofty personal aspirations that enable them to judge rightly and live with noble purpose. "Science can only ascertain what *is*, but not what *should be*," he said.[9] Both are important, but they should not be confused.

EDUCATING YOUNG PEOPLE IN SCIENCE WILL EQUIP THEM TO PARTICIPATE MORE FULLY IN THE PUBLIC DEBATE.

Most parents want their children to succeed as individuals, a goal that requires them to learn about scientific principles as well as religious beliefs. To deny children the right to appreciate the beauty and importance of our natural world and understand how it works is to stunt their growth intentionally. Educating young people in science will equip them to participate more fully in the public debate. It will help them to understand the consequences of failing to care for our limited natural resources, as well as to make informed choices about the alternatives. It will help instill in them skills important to science, such as problem solving and critical thinking, which will also serve them well in the workforce.

What might parents do to advance their children's scientific literacy? Pay closer attention to what their children are learning in science classes, and encourage their teachers to utilize the growing list of resources that are available. For the past 25 years, the National Science Resources Center (NSRC) has leveraged the research and expertise of the Smithsonian and the National Academies to develop science education programs. These programs are now part of the K–12 science curriculum of more than 1,200 school districts across 48 states, representing 30 percent of the U.S. student population, and are also used overseas in nine countries. The Smithsonian is also working with the Council of Chief State School Officers (CCSSO) to develop new instructional materials and offer teachers professional development that addresses common core state standards. Our Smithsonian Center for Education and Museum Studies (SCEMS) reaches hundreds of thousands of students each year.

Parents should also spark informal learning through visits to local natural history and science museums or planetariums, and look for interactive, family-oriented exhibits. For example, the Smithsonian's National Museum of American History offers "Invention at Play," an exhibition for families in our new Lemelson Center for the Study of Invention and Innovation. It has highly interactive and engaging activities that focus on the creative skills and processes used by inventors. The museum also offers "Spark!Lab," the newest hands-on space where families and others can play games, conduct science experiments, and explore inventors' notebooks. Many museums across the country offer similar opportunities and suggestions for families.

Parents can also respond to children's questions about how things work, helping children to form conceptual models that let them see how the pieces fit together. Encourage curiosity about the natural world with a simple walk in a park. Teach by example behavior that is meaningful or personally relevant to them as individuals — whether it is planting a garden or recycling — and beneficial to society. Ideas and resources are plentiful.

To cite just one example: In 2003, the American Association for the Advancement of Science, with TryScience.org and funding from the National Science Foundation, launched the Partnership for Science Literacy. It is designed to increase public awareness among parents, families, and caregivers of the value and importance of scientific literacy for every child. Among other things, it offers a website and a free family guide to science, which is available in English and Spanish.

Media: Increasing Coverage

Beyond formal education, where do Americans go to learn about science and technology? Many of us depend on the news media to keep us abreast of advances and breakthroughs, to explain the science behind erupting volcanoes or the engineering involved in containing massive oil spills. The rights of the media are protected under the Constitution's First Amendment, but I believe that they also have a responsibility to devote adequate time and space to science and technology news, particularly as they are applied to areas such as the environment, medicine, and public health. These stories are not always easy to cover, requiring an investment of time by reporters well versed in their subject.

While they may not be scientists themselves, science writers can make an important difference in how the public understands complex issues. The recent work of Chris Mooney, author of the paper "Do Scientists Understand the Public?" written for the American Academy of Arts and Sciences, is a good example. Chris is also the co-author, with Sheril Kirshenbaum, of *Unscientific America: How Scientific Illiteracy Threatens Our Future.*[10] Such writers have a talent for describing a complicated subject so that the non-expert can understand.

In my role as chair of the National Research Council's study of the hurricane protection system for New Orleans, I found that writers from the *Times Picayune* and *The New York Times* were often better at explaining the issues to the public than the experts. During the course of my involvement in New Orleans, I was interviewed by reporters from both newspapers and found that they reported the stories accurately and explained clearly the context and meaning of engineering concepts such as the "probability of uncertainty surrounding the risk associated with levee overtopping."

To their credit, there are media sources working to help the public understand science. The "Science Times" section of *The New York Times; National Geographic* magazine; and PBS's "Nature," "NOVA," and "Scientific American Frontiers" programs are good examples. Still, their audience is often limited, and as Americans rely more on the Internet and less on traditional media for information, budget cuts at other media outlets have reduced the time and space devoted to science and technology. We need to think about how we can reach out to the larger public using new technology and new approaches.

Scientists and Engineers: Active Listening, Better Communication

Scientists and engineers also have rights and responsibilities. Universities provide professors and students with academic freedom to express their conclusions and opinions, and that is as it should be. They have ample opportunities to explore the unknown through research and to share their findings with their professional colleagues and the public alike. But if we are ever to close the gap between science as it is practiced and the public's understanding of it, scientists must accept the responsibility of communicating their advances in clear language understandable to the average layperson. Their communication must include both the positive and beneficial outcomes of their work and the potential negative consequences of science and technology. Universities should make this responsibility clear to faculty members from their first contact in recruitment and orientation, provide training to help them accomplish it, and encourage and reward excellent communication throughout their academic careers. Similar expectations should apply to researchers working for government organizations, nonprofits, and industry. While many scientists and engineers are sensitive to the possibility that opponents of a change may exploit the discussion of negative consequences, it is far better to have an honest and open discussion early on than to risk the perception that the scientific community withheld information.

The tendency for scientists and engineers to avoid open debate is often associated with the more pernicious characteristic of arrogance. Nowhere was this more obvious than in the e-mails, disclosed in 2009, of scientists working on climate change research. The content was openly derisive of climate change skeptics and concerned about how the skeptics might use the scientists' data against them.[11] Unfortunately, such attitudes are not an anomaly within the science community, and they hinder the effort to find common ground. If scientists and engineers are to receive strong public support for their efforts to solve global problems and improve lives, then they have a responsibility to listen to all voices, even those that seemingly attack science. Dissent can be a good thing, expanding everyone's understanding of the content and the issues, but only if everyone is willing to listen as well as speak, and the debate is as respectful as it is vigorous.

IF SCIENTISTS AND ENGINEERS ARE TO RECEIVE STRONG PUBLIC SUPPORT FOR THEIR EFFORTS TO SOLVE GLOBAL PROBLEMS AND IMPROVE LIVES, THEN THEY HAVE A RESPONSIBILITY TO LISTEN TO ALL VOICES.

We are fortunate that the vast majority of scientists are good citizens, and many understand the issue of scientific literacy and accept the responsibility to help. The book *Physics for Future Presidents,* by physics professor Richard A. Muller, is an excellent primer on matters ranging from climate change to biological terrorism. Muller has written it so an average person can understand and form opinions on the policy alternatives for addressing complex matters of science.[12] Other writers like John McPhee and Tim Flannery have given us outstanding books that address the most complex of science topics, such as plate tectonics and climate change, in ways that allow an average person to grasp the fundamentals.[13]

Beyond the written work of scientists, interested citizens gather on a regular basis in a hundred "science cafes" in local communities across the United States to hear presentations by scientists about timely issues and to engage in conversation with them.[14] Students are also benefiting from the willingness of scientists and engineers to visit local classrooms to discuss the rich rewards of careers in those fields and share their stories of exploration and discovery. By sharing what they know with both candor and clarity, scientists can do much to improve the state of scientific literacy in America — and we depend on them to do so.

RENEWED ROLE FOR INSTITUTIONS

In addition to parents, media, and individual scientists and engineers who exercise their responsibilities as well as their rights, we also need institutions such as professional societies, universities, and museums to step forward as the tidal wave of information builds.

Professional Societies: Ensuring Lifelong Learning

The professional societies that host conferences and publish journals are the "watering holes" for engineers and scientists. As these organizations exercise their right to address their constituents and ensure lifelong learning, they should also assume a collective responsibility to serve the public's need for a basic understanding of and balanced views on the scientific and technical matters of the day. In part, this is the focus of Project 2061, founded in 1985 by the American Association for the Advancement of Science to help all Americans become more literate in science, mathematics, and technology.

The responsibility goes beyond the occasional article about the importance of scientific integrity to include an editorial view that emphasizes the impact of scientific results. This expanded role is particularly important now that professional societies can use the Internet to distribute educational materials to teachers and students. For all of our sakes, the content of such offerings must undergo a professional evaluation to ensure that they present a balanced perspective about the benefits and downsides of science and technology.

Institutions that educate, formally and informally, have a responsibility to ensure that each course or exhibit has the potential to transfer a particular body of knowledge from an expert source to a group of individuals seeking understanding. But they also have a larger responsibility to make sure that the cumulative impact of the knowledge they impart serves the public good. This responsibility is largely overlooked in the press of day-to-day activities and making sure the bills are paid. Who takes responsibility to see that the totality of an institution's offerings has an additive positive effect? Those in charge should, and there should be a formal process to ensure it.

Universities: Enhancing Scientific Understanding across Audiences

Universities have a built-in advantage in helping improve scientific literacy. They have students studying both scientific and non-scientific disciplines, and they reach out to alumni and other broader audiences, particularly using digital technologies. However, for too long they have not seen it as their responsibility to take an institutional approach to scientific literacy. I contend that this responsibility involves not only helping students in non-science majors understand science, but also helping students who are science and engineering majors understand the place of science in society. In addition, it involves an institutional commitment to help the general public understand the findings of faculty research. Universities often proclaim their right to pursue unfettered research inquiries, but then do far too little to communicate the consequences of those outcomes to the public — the very entity that funded the work with its tax dollars. This situation needs immediate attention if universities are to maintain public support.

Before I became secretary of the Smithsonian Institution, I had the good fortune to serve as president of the Georgia Institute of Technology. It took me a while to begin to appreciate the larger responsibilities incumbent on a public research university. One of these related to the educational experience we provided to our bright and talented undergraduate students.

Faculty, academic administrators, students, parents of the students, alumni, and employers all had opinions, many contradictory, about who should shape the undergraduate experience. It seemed to be everybody's responsibility, and thus it was nobody's responsibility. Beyond the details of majors and curricula, the broader institutional question for a school like Georgia Tech was: How can we help our very bright, technically inclined students gain the larger knowledge and perspectives that will help them become productive citizens of society and the world? This challenge is in essence the reverse side of scientific literacy. A student who enrolls at Georgia Tech is automatically interested in learning about science and engineering and prepared to develop a deep knowledge of the fundamentals. Yet such students also need to realize their obligations to understand how science will be used and to what ends — topics that often exceed the charge of most faculty, who are principally concerned with competency in narrow subjects. I believe that the responsibility for instilling this broader perspective lies with a university itself.

To achieve this goal, universities need to create an educational environment that extends beyond the conventional curriculum and encourages undergraduates to experiment intellectually, teaching them to confront new ideas and respond to people whose opinions differ from their own. This environment must be challenging and uphold academic rigor while simultaneously offering the best of informal education. The idea may seem simple, but it is rarely used in a holistic way in most universities.

At Georgia Tech, we developed an organizational structure that supported this goal. A new Office of the Vice Provost for Undergraduate Studies was given responsibility for the totality of our undergraduate curriculum, ensuring that it led to a graduate from any major who was prepared not just for a job, but for life. We emphasized increased opportunities for study abroad, undergraduate research, and engagement in the arts and humanities, including performing arts, poetry, and languages. At the same time, the existing Office of the Vice President for Student Affairs expanded informal learning opportunities outside the classroom and laboratory with thoughtfully conceived extracurricular activities that promoted leadership, health and fitness, and volunteerism, and provided forums to discuss issues of the day. Without any reduction in academic standards, retention and graduation rates increased; program rankings and student satisfaction improved; outstanding faculty came through our doors to join in the new approach; and student participation in voluntary music and poetry activities rose dramatically. Most important, surveys of graduates five years out showed that they felt this broader approach to education was important to their lives and to their ability to succeed in a global economy.

We also applied the idea of taking greater responsibility for scientific literacy to outreach programs for K–12 schools and in communicating the impact of our research. An organization was formed for this purpose, reporting to the College of Sciences; this construct insured that the work honed in on science principles and the latest research outcomes. It assisted faculty in reaching out to the K–12 system by providing a coordinated approach through professionals who knew the needs of the teachers. I was proud of the accomplishments of our outreach programs, but know we could have done more. Sadly, the onslaught of state budget cuts brought on by the realities of economic recession is placing public university outreach efforts under pressure or eliminating them entirely at a time when the need has never been greater.

I would argue that even under challenging budget circumstances, universities have a collective responsibility to improve scientific literacy as a part of their commitment to society. Thomas Jefferson understood this responsibility and attempted to incorporate provisions for it into his plan for the University of Virginia. He felt that the university should allow average citizens to return to its classrooms from time to time to learn about new developments. Beyond traditional continuing education, universities can do what Jefferson had in mind through their alumni associations and non-traditional programs. The possibilities are enhanced by the growing capabilities of digital technology to deliver learning any place, anywhere, anytime.

To its credit, the National Science Foundation requires that all universities who receive funding for research include an outreach component in every science or engineering project. This mandate is well intended, but remains largely ineffective. Too often, piecemeal, token outreach efforts by individual faculty untrained in communicating science simply do not make an impact. It is essential that the university as a whole is serious about its responsibility to promote scientific literacy. Universities should take stock of the effectiveness of the outreach activities they have underway, identify gaps and fill them, and formulate a plan to improve coordination. Working collectively, they can make a difference, and they have an obligation to do so.

Public Museums: Using New Tools to Broaden Reach

In the effort to raise the level of scientific literacy and broaden Americans' view of the world, public museums represent a virtually untapped resource. In their work, museums should be true to their institutional ideals as they present the world through the eyes of artists, scholars, and scientists. Their governing boards should support this philosophy. However, they also have a broader responsibility. With their vast collections, tremendous reservoir of expertise, and crowd-pleasing exhibitions, museums are a perfect venue from which to conduct informal education and to assist an overburdened educational system in enlivening classroom offerings.

Because of their nature, museums reach a larger demographic than the typical university, and those who come to visit are often in family groups. This visitor profile gives museums a unique opportunity to educate through family interactions that reach beyond the perspective of a lone individual. Museums also have a responsibility to help their visitors become involved and engaged in the world around them and understand the issues we face as a species.

Beyond the conventional museum visit, museums have an enormous opportunity to use digital communication tools to reach new audiences. Digital technology is not only a new option to expand communication, it is also a tool for reaching those who normally do not, or cannot afford to, make a personal visit. As museums extend their reach using digital technology, they should incorporate the use of interactive social media for two-way communication between their curators and scholars and the public. This approach represents a shift from the past, when curators and scholars largely remained an abstract presence behind the exhibit walls.

Imagine a museum where the collections are digitized so that they may be accessed by teachers and learners alike, where images are three-dimensional and can be manipulated by the user. Butterflies are more than beautiful static images; they fly off into the natural environment in which they live. Scientists can share information about the evolution of a species over millions of years, showing genetic changes over time. Students and teachers work with content experts in a digital space to design experiments, which they then carry out in nearby nature preserves with native species the students can see firsthand. Using gaming techniques, students can challenge each other to solve intriguing problems with information from museum collections.

Rapidly emerging technology makes exciting and dynamic educational initiatives possible. To their credit, many museums are beginning to develop new approaches to engaging learners and helping them understand complex issues. Yet much more needs to be done if we are to take advantage of present and future technological advances.

The special subset of museums that focus on science and technology has long worked to address the issue of scientific literacy. In the future, museums need to join forces with others to make a bigger difference, especially as they capitalize on the possibilities of digital outreach.

The Smithsonian: Purposing Resources to Educate and Engage

As secretary of the Smithsonian, I am awed daily by its intellectual resources and its power to engage both experts and laypeople in dialog. The Institution has an astounding number of moving parts: 19 museums; the National Zoo; 20 libraries; multiple research centers; activities in nearly 100 countries; and collections containing 137 million objects, specimens, and works of art. Energized by creative research scientists and scholars working around the world, the Smithsonian's scientific research enterprise encompasses astrophysics, astronomy, zoology, biology, paleobiology, anthropology, geology, ecology, museum collection research and care, and marine science. In addition to the National Museum of Natural History, the National Air and Space Museum, and the Zoo, all headquartered in the nation's capital, we have the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts; the Smithsonian Tropical Research Institute in Panama; the Smithsonian Environmental Research Center in Edgewater, Maryland; the Smithsonian Conservation Biology Institute in Front Royal, Virginia; the Museum Conservation Institute in Suitland, Maryland; and the Smithsonian Marine Station in Fort Pierce, Florida.

As I learned more about the Smithsonian, I began to appreciate its untapped potential. The Smithsonian is unique in its ability to synthesize knowledge across disciplines and, as opposed to the great universities, its capacity to consider issues within their own time frame rather than the time frame of research grant cycles. Nevertheless, the Institution was absorbed in day-to-day operations, not thinking about the long-term future, and doing little work that connected its museums and research centers.

ENERGIZED BY CREATIVE RESEARCH SCIENTISTS AND SCHOLARS WORKING AROUND THE WORLD, THE SMITHSONIAN'S SCIENTIFIC RESEARCH ENTERPRISE ENCOMPASSES ASTROPHYSICS, ASTRONOMY, ZOOLOGY, BIOLOGY, PALEOBIOLOGY, ANTHROPOLOGY, GEOLOGY, ECOLOGY, MUSEUM COLLECTION RESEARCH AND CARE, AND MARINE SCIENCE.

To make the best possible use of our resources, as well as to meet our responsibilities to society, the Smithsonian needed to undertake a comprehensive strategic planning process that was inclusive and allowed for the staff of the wide array of museums and centers to think together about the future. A steering committee of Smithsonian employees developed a creative process that also involved thoughtful people from outside the Smithsonian. It was exciting to see people from the many different disciplines and units at the Smithsonian welcome the opportunity to think about how a venerable institution could become creative and vibrant and relevant to many of our nation's and the world's most challenging issues.

The result was a new strategic plan that gathered the varied activities of the Smithsonian into four grand challenges: Unlocking the Mysteries of the Universe, Understanding and Sustaining a Biodiverse Planet, Valuing World Cultures, and Understanding the American Experience. These four challenges neatly capture our core pursuits and offer opportunities that had not existed before — opportunities for cross-disciplinary collaboration among scholars both within the Smithsonian and outside of it. They also pose a structure for delivery of education about not only history, art, and culture, but also the sciences and how these disciplines interact to form the body of interlinked knowledge that comprises what we as humans know about our world.

The new strategic plan offers the Smithsonian an exciting vision for its future — one that calls for us to address the world's most challenging issues, to enhance our role as an educator and integrator of knowledge, and to help both our scientists and the public see beyond the silos of ever-narrowing fields of study. Even more exciting, the plan also details how we can take advantage of digital technology to bring the vast resources of the Smithsonian to people who cannot or do not personally visit us. This approach provides the Smithsonian a unique opportunity to help address the problem of scientific literacy.

Can we deliver on this new vision? It requires new funding in a challenging economic environment, but I am very optimistic about our future. The Smithsonian's breadth and depth prepare us to play a leadership role in helping our nation to understand the new world of science. We are already putting scientists and researchers directly on the museum floor to work with youngsters and adults alike, conducting hands-on experiments or exploring questions related to exhibition themes. We are investing time in formal training to help the nation's teachers access and make the best use of our scientific resources, as well as sending those resources into classrooms across the country — both physically and virtually. Education is a top Smithsonian priority, and we are eager to convene our peers to share what we have learned and benefit from what they have done as well. Emblematic of our commitment is our recent creation of the position of assistant secretary for education and access, a leader who will coordinate the Smithsonian's widely based educational activities and ensure that we lead in the use of innovative approaches for learners of all ages.

AMERICA AT THE CROSSROADS

Our nation is at a critical juncture. Science and technology are essential to our future, yet America as a whole is losing its confidence in scientists at a time when the accumulating negative consequences of past developments pose an ever-growing threat. Waning scientific literacy further clouds the debate. Developed over the past two hundred years into a powerful engine, science is now devolving into ever-smaller specialties and becoming increasingly opaque to a public whose need to understand what is happening grows more urgent. Many institutions and agencies have become aware of the problem and are beginning to work toward a solution, but the absence of coordination and common purpose marginalizes their impact.

The times require all those whose efforts are needed to step forward and accept the responsibility to improve the level of scientific literacy. Families, scientists and engineers, professional organizations, universities, research organizations, and museums all have skin in the game and need to link arms to meet the challenge. All must aim their efforts at providing a rich array of formal and informal opportunities for citizens of all ages to improve their scientific literacy, and at greatly expanding opportunities for public discussion and debate about the future directions of science. Such discussions should bring together scientists and laypeople who have a vested interest in science, and should take place at all levels, from local science cafes to national summits.

Finally, there has never been a greater need to seek common ground with those who are doubtful about science. If we are to succeed in opening a dialog, we will need to speak with clarity about the uncertainty in science and about the potential negative consequences of scientific advances. We should also listen carefully to those outside the science enterprise and recognize that there is no monolithic viewpoint, but rather a full spectrum of views that should be included so that the issues are clearly stated and the causes are understood.

IF PEOPLE AND INSTITUTIONS HAVE THE WILL AND ACCEPT THEIR RESPONSIBILITIES, THEN WE CAN TURN THE TIDE FOR SCIENTIFIC LITERACY. TIME IS NOT OUR ALLY, AND ACTION IS NEEDED NOW. AT THE SMITHSONIAN, WE ARE PREPARED TO TAKE IT.

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