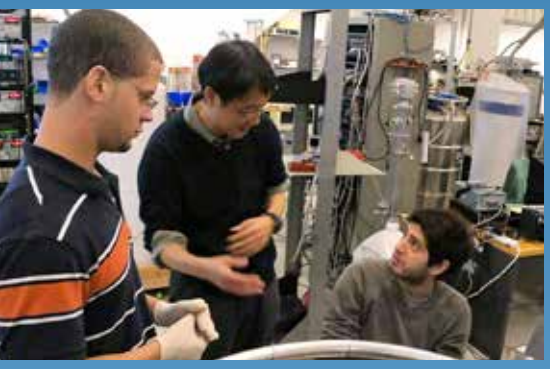
COLUMBIA | SCIENCE






Achieving Preeminence in Science

Strategic Plan for Science in the Arts and Sciences
Executive Summary

Life—from proteins to populations

Mind Brain Behavior

MOLECULAR ARCHITECTURES—
FROM ATOMS TO DEVICES

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Achieving Preeminence in Science:

Strategic Plan for Science in the Arts and Sciences

Executive Summary

INTRODUCTION

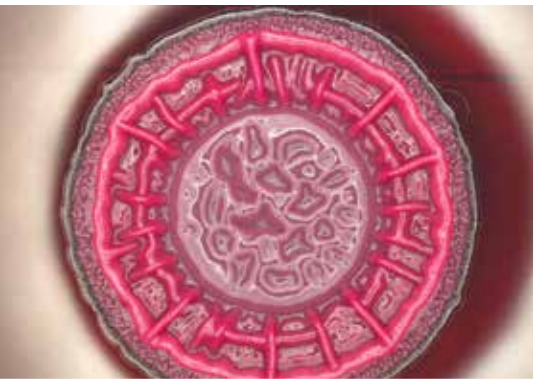
Many of the world's greatest discoveries have been made in the nine natural sciences departments in the Arts and Sciences at Columbia University. Collectively, our faculty members have won numerous Nobel Prizes and are disproportionately represented in the National Academy of Sciences and the American Academy of Arts and Sciences. In many cases Columbia's science departments are among the top in their fields globally, and they have played essential roles in the advancement of science.

Building on this distinguished history, we have developed a plan to renew Columbia's science leadership and achieve scientific preeminence over the next decade. This renewal will be accomplished through groundbreaking research that will expand knowledge and solve critical problems. At the same time, this plan will enhance research opportunities for our undergraduates that will instill critical thinking skills, foster the next generation of scientists, and better inform the public, whose understanding of scientific issues that impact society is essential to a robust democracy.

This plan will improve Columbia's research competitiveness in an ever-more-difficult federal funding climate, increase diversity in our scientific community, enhance opportunities for technology transfer and commercial partnerships, and build synergistic relationships between science and other intellectual pursuits at Columbia. Given its preeminence in humanistic studies such as law, philosophy, and ethics, Columbia is an intellectually robust community for holistically considering the ideas generated through scientific discovery.

There are 215 natural sciences faculty members in our nine departments:

- Astronomy
- Biological Sciences
- Chemistry
- Earth and Environmental Sciences
- Ecology, Evolution and Environmental Biology
- Mathematics
- Physics
- Psychology
- Statistics







Strategic Plan—Why Now?

Columbia University has laid the groundwork for decades of expansion through the construction of the Manhattanville campus and the recently completed Northwest Corner Building on the Morningside campus, which is devoted to interdisciplinary research. With many areas of science at the brink of new discoveries, and with an unusual number of retirements approaching in the nine departments, the natural sciences are primed to lead Columbia's expansion with a bold vision for the future.

The traditional delineations between scientific disciplines are increasingly blurred. Research is becoming both more globally collaborative and competitive, while new technologies have opened uncharted territories. Chemistry is becoming more computational and converging with engineering and commerce to design powerful new materials that could change the future of energy and medicine. Biology is evolving from a descriptive science to a quantitative one, driven by massive data sets and sophisticated modeling that makes use of tools from chemistry, physics, engineering, and computer science. Physics is on the verge of unlocking the deepest foundations of the universe through increasingly international collaborations focused on designing powerful new instruments and techniques that store and manage some of the largest data sets in history. The environmental sciences have become integrally linked to political science, law, economics, and urban planning.

With the development of new technologies, researchers can now address questions that were previously unanswerable, from atomic structures of materials to the possibility of life on other planets. Nanoscience has become the gateway for inventing two-dimensional materials that may replace silicon and unleash the next revolution in electronics. Similarly, our new abilities to probe biological systems have enabled researchers to create a motion picture of the brain's circuitry that heralds a new era in neuroscience and psychology. Scientists are also researching mechanical systems that incorporate living cells and that could harness

untapped sources of mechanical energy. Biologists are now unlocking new avenues for treating previously incurable diseases due to our ability to design new kinds of drugs. Finally, because of new astrophysical technologies, scientists are discovering Earth-sized planets that could have atmospheres and other essential ingredients of life, while studies of the early Earth reveal the pathways for the emergence of life on this planet.

New Initiatives

This plan puts forth a coherent set of new initiatives and programs that capitalize on the opportunities for growth outlined above and aim to increase the intellectual depth, interaction, and inventiveness of Columbia science. We lay the groundwork for creating three major new Columbia institutes, each of which builds on Columbia's existing strengths and the potential for revolutionary breakthroughs in the next decade that will have major significance for humanity. We also identify ways that growth in the Arts and Sciences will strengthen and support existing and planned Columbia institutes. We include innovative strategies for recruiting outstanding faculty, including a new interdisciplinary faculty initiative. We establish new shared facilities that will support research across a wide range of disciplinary and interdisciplinary programs. We have initiated a new Columbia Prize Fellows program akin to the Harvard Society of Fellows and are developing additional programs to improve administrative efficiency and laboratory infrastructure. The Arts and Sciences has new leadership in science that will support and encourage interaction within and between schools and institutes. This broad set of actions will enable us to apply resources toward meeting our goals and objectives in science research more effectively.

The Planning Process

For the first time the natural sciences departments at Columbia University have put forth a unified plan for the future of the basic sciences at the University. This strategic plan is the result of a collaboration among the nine departments that began in February 2012 and has invited input from all of the science faculty in the Arts and Sciences.

Objectives

The natural sciences departments have identified three primary objectives that will set new directions for science over the next ten years and secure Columbia's place as a research university, preeminent among top ten peers worldwide.

1. To increase and sustain excellence in science research and to be a magnet for top science faculty, researchers, and students throughout the world

2. To increase the role research plays in educating undergraduate students and to increase research opportunities for graduate students

3. To contribute solutions to today's problems through the dissemination and application of new discoveries

STRATEGY

This plan puts forth major strategies and a coherent set of new initiatives and programs aimed at further increasing the intellectual depth, interaction, and impact of Columbia science.

Faculty Size

Research excellence is determined not only by the quality of the individual scientists but also by the number of such researchers working together. To achieve scientific preeminence at Columbia, we need to increase the faculty size by roughly 20 percent over the next decade. This expansion will be focused on departments that will benefit most from a greater breadth of expertise in disciplinary and interdisciplinary areas as well as building strength in important subdisciplines.

Faculty Quality

An outstanding faculty is the engine behind world-changing research. Existing top faculty, high-quality shared research facilities, excellent administrative support structures, and a collaborative environment will make it possible for our departments to continue to attract leading figures and rising academic stars. Due to retirements and department growth, roughly 40 percent of the natural sciences faculty will be new hires within the next decade. This plan ensures they will be of the highest caliber in the world.

Six Research Themes

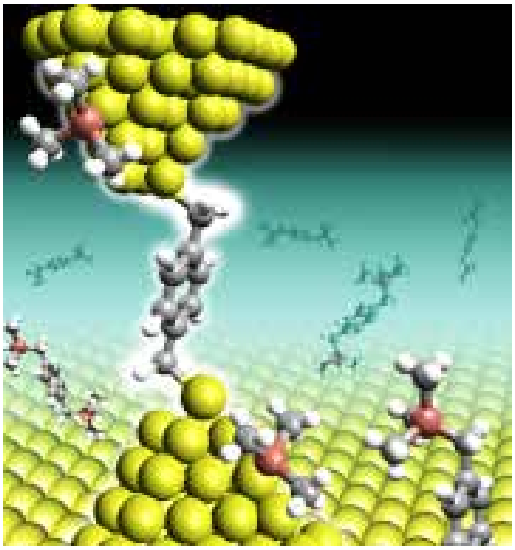
We have identified six major research themes that reflect common areas of investigation with exciting promise at Columbia. The first three themes lay the groundwork for creating new Columbia institutes led by the Arts and Sciences. The second three themes provide opportunities for growth in new directions that draw Arts and Sciences into important collaborations with three major existing Columbia initiatives.

MOLECULAR ARCHITECTURES—FROM ATOMS TO DEVICES

Materials—be they metals, minerals, polymers, or plastics—are the building blocks of our future. They are the basis for entire industries and countless modern comforts, and they underpin our ability to explore space and the ocean depths. With the advent of nanoscience, researchers have begun to examine and build materials one atom and one molecule at a time. This allows researchers to probe the fundamental nature of matter and to use that information to invent materials with unprecedented and predictable characteristics.

One important nanoscale problem our chemists, physicists, and engineers are trying to solve is how best to replace silicon, enabling us to make even smaller semiconductors. At stake is the continued progress of the electronic and information-processing revolution. Promising carbon-based materials include atom-thick graphene, which not only is the strongest material ever discovered, but also possesses remarkable electrical properties.

In addition to fabricating materials, researchers are inventing new medical devices and finding better ways to harness alternative energy sources. For example, single-molecule biosensors that run a current through a one-dimensional wire embedded with a strand of DNA can quickly diagnose diseases in the field (such as trachoma, a major cause of blindness in Africa) or detect biological weapons. Foreshadowing exciting advances in alternative energy, a new technique has just demonstrated the capability of transforming a single photon into two electrons. With the right engineering solutions, solar energy efficiency could be pushed well past the current 35 percent threshold.



The potential for life-changing science and technology emerging from work on the nanoscale is enormous. Given Columbia's substantial existing strength in this field, investments will accelerate Columbia's programs to the forefront of the next generation of exciting discoveries.

LIFE—FROM PROTEINS TO POPULATIONS

There is scientific truth in the adage that we are all connected through the web of life. And now new interdisciplinary research methods and new technologies have positioned us for breakthroughs in understanding that web—which spans from the function of a single cell to the remarkable complexity of an ecosystem.

An important example of that intellectual intersection lies in human biology. By applying tools provided by chemistry, physics, engineering, and computer science, biologists are now developing the means to control, with drugs, proteins that were previously viewed as inaccessible. Understanding and controlling these proteins promises the potential to treat previously incurable diseases.

Similarly, biologists studying natural systems are now fusing their research with that of engineers and physicists to explore new frontiers in energy research. For example, the mechanical energy produced during evaporation by a particular spore may represent a completely new form of harnessable alternative energy.

Technological advances underpin these and other pioneering research pathways. For example, the new observational power of high-intensity lasers makes it possible for neuroscientists to examine the operation of the brain in real time. This opens the door to understanding the rules that make the brain's trillions of electrochemical events work together to produce human thoughts, emotions, and actions.

Columbia researchers are also trying to understand the extraordinary chemical complexity of the oceans and what causes them to absorb one-third of the atmosphere's carbon dioxide—a global process critical to our planet's climate stability. Microscopic life forms control the biogeochemical balance in the surface ocean, but how they do it—and in turn help regulate the atmosphere's concentration of carbon dioxide—is unclear. This plan brings such researchers together and significantly expands the potential for understanding how microscopic and massive processes impact one another, progress that will be critical to solving many of the central problems facing society today.

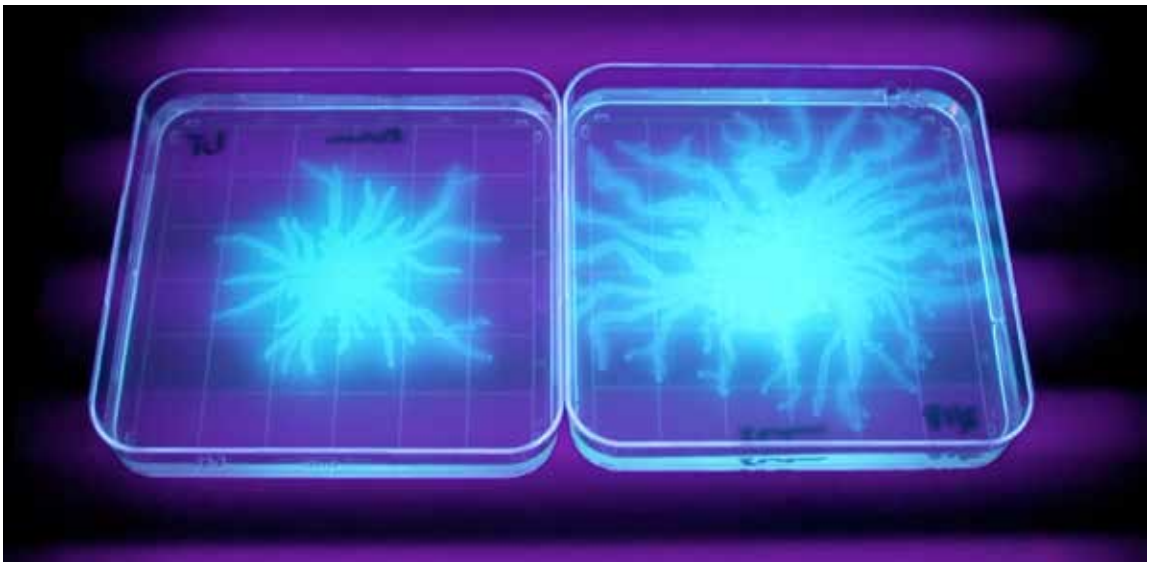
ORIGINS—FROM THE BIRTH OF THE UNIVERSE TO THE BEGINNING OF LIFE

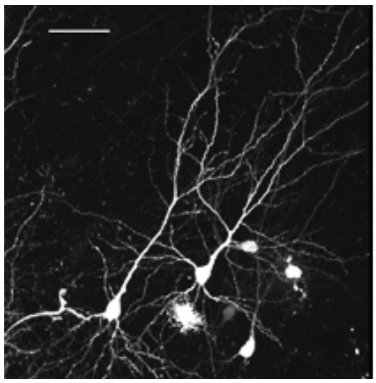
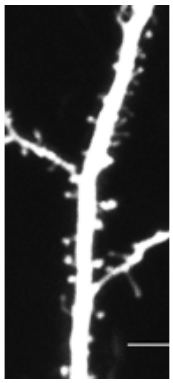
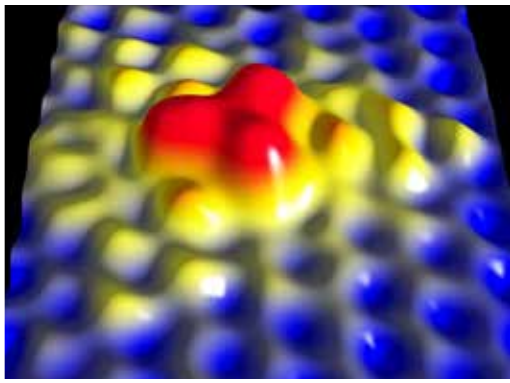
Researchers are on the brink of answering some of humankind's most fundamental questions about its origins and uniqueness within the universe: Is there life on other planets? What caused the Big Bang? What is space? What is time? What are dark energy and dark matter?

Columbia scientists played a considerable role in demonstrating a robust detection of the Higgs boson—the only elementary particle predicted by the Standard Model of particle physics that, until July 2012, had not been found. This recent discovery explains the existence of mass in the universe and brings us a step closer to understanding the underlying makeup of the universe.

Within a decade scientists will likely observe signatures from the universe dating to when it was much less than one second old, revealing important clues about what caused the Big Bang. This research on the early universe will in turn inform efforts by theoretical physicists and mathematicians striving to uncover the mathematical nature of space and time.

Scientists are also conducting experiments both in outer space and in deep underground mines in order to detect dark matter particles. Their research is close to answering one of the most alluring questions in astrophysics—What is dark matter? They are also employing powerful new astronomical surveying tools designed to reveal the nature of dark energy—another great mystery whose resolution holds clues to the nature of gravity and the ultimate fate of the universe.



Meanwhile, in anticipation of discovering hundreds of Earth-sized planets in other solar systems that could potentially sustain intelligent life, astrophysicists are exploring how planets form and are developing techniques to determine which planets have atmospheres and other conditions for life. At the same time, scientists are investigating the emergence of life on Earth.

This plan facilitates substantial growth in interaction between theorists and experimentalists working across an increasingly broad range of fields, bringing Columbia to the forefront of research on these mind-expanding topics.

MIND BRAIN BEHAVIOR

The human brain is arguably the most complex living structure on the planet. The study of the mind has moved beyond molecular analysis toward investigating ensembles of neurons whose concerted actions underlie the complexity of human behavior and thought. Neural circuits must, in some way, account for high-level functions such as memory, self-awareness, language, joy, depression, and anger. By establishing the Mortimer B. Zuckerman Mind Brain Behavior Institute, under the leadership of the neuroscience department of Columbia University Medical Center, Columbia is expanding the realm of traditional neuroscience to encompass other fields within the natural sciences.

Exciting current research in Arts and Sciences includes psychologists looking at the intersection between learning, memory, and decision-making by studying the impact that past experience and explicit knowledge has on one's decisions and by examining how perception in the brain is accomplished during social communication by songbirds.

Through its new Grossman Center for Statistics of Mind, the statistics department will partner with the Zuckerman Institute. Statisticians are helping answer some of the fundamental questions in neuroscience. Given an input stimulus (a movement, thought, etc.), what is the conditional probability of a neural response? With a finite number of possible inputs, statistics can help decipher the neural codebook.

As the Zuckerman Institute gets under way, the Arts and Sciences will play an increasingly essential role in connecting traditional neuroscientists with their colleagues in the other natural sciences.

DATA SCIENCES

Living in the Information Age, we are confronted with unprecedented access to the breadth of humanity's knowledge. That incredible connectivity is fueled by our ever-faster computing power, which yields ever-larger amounts of data. The field of data science has emerged to extract meaning from and efficiently handle that data.

The University's recent launch of the Institute for Data Sciences and Engineering (IDSE)—an interdisciplinary endeavor lead by The Fu Foundation School of Engineering and Applied Science that will address the

immense challenges and opportunities posed by our data-rich society—offers significant opportunities for collaboration with the Arts and Sciences. The natural sciences will play an important role in at least four of the five new IDSE centers. The Smart Cities Center will incorporate research by the Departments of Earth and Environmental Sciences and Ecology, Evolution and Environmental Biology, and, potentially, Psychology. The Health Analytics Center will include collaboration with the Departments of Chemistry and Biological Sciences. And the Financial Analytics Center will cover topics significant to the joint financial engineering degree, in which math department faculty will play a significant role. Finally, the Center on the Foundations of Data Science will draw on the expertise of faculty in a broad range of fields, including statistics, math, physics, and other departments.

The explosion in computational power, and in instrumentation for data collection in particular, impacts all areas of science. No research university can hope to achieve and maintain a preeminent position in science without strong collaboration between statisticians and data scientists and a wide array of data-rich fields. The development of the Institute for Data Sciences and Engineering, working in close collaboration with Arts and Sciences, is timely and has great potential for positioning Columbia at the forefront of this important direction of research.

EARTH

The planet and its inhabitants face a dire prognosis: by 2050, nine billion people—many of whom will struggle in deep poverty—will vie for the earth's waning resources while the full impact of climate change begins to take effect. Columbia's Earth Institute, including the world-leading Lamont-Doherty Earth Observatory, works to help guide the world onto a path toward sustainability through research in public health, poverty, energy, ecosystems, climate, natural hazards, and urbanization.

Much of Columbia's basic research on climate and resources takes place in Arts and Sciences, which will play an increasingly major role in studying better ways to understand and adapt to climate change, protect our oceans and other ecosystems, and advance alternative energy sources and sequester carbon. As dense populations settle along coastlines, riverbanks, and steep slopes, we will continue to develop methods to predict the risks posed by earthquakes, landslides, major storms, and tsunamis.

Arts and Sciences research will be broadened by new collaborations with other Columbia departments and institutions, such as using advances in genomics research in the biological and medical sciences at Columbia to study cellular-level responses to ocean acidification and the effects of biodiversity loss on populations. Other collaborations include research on environmental decision-making and examining human interactions with the environment through the lens of social psychology. Studies of Earth also use the tools of statistics and data analysis extensively and will foster strong ties to the research conducted through the IDSE.

This theme, a primary aspiration of many of our students, is driven by the need for effective stewardship of the planet and for creating sustainable communities based on renewable resources.

Targeted Research Areas

Many of the world's modern challenges require solutions that cut across traditional disciplines. However, all interdisciplinary collaborations rest on the strong disciplinary foundations that our scientists build in their respective fields. Each department has identified subdisciplines where growth has the potential for great impact. The result appears in individual departmental plans included as appendices to the full report. Some of this growth will be facilitated by new centers, and some by pillars of strength within or between departments. Targeted research goals will be achieved through strategic hiring practices such as targeted recruitments and cluster searches, as well as by fostering good departmental planning in order to build or maintain sufficiently large faculties to achieve and maintain preeminence in critical subfields.

The Role of Centers and Institutes: Planning, Management, Collaboration, Partnerships

The proposed centers and institutes will bring researchers together to tackle important new ideas and ensure that there is a critical range of expertise to forge innovative areas of research. They will provide essential support for new shared facilities and the administrative structure required to apply for and ultimately administer large center grants, while adhering to their safety and compliance requirements. The centers and institutes will provide support for outstanding visiting scholars and create a rich and interactive environment for undergraduates and graduate students.

Facilities

Outstanding shared research facilities are at the core of Columbia's scientific institutes. We propose new shared facilities that will support activity across Columbia and enhance our research competitiveness. Shown in parentheses below are the leading new themes driving the development of each facility:

- Nanofabrication Laboratory (Molecular Architecture)
- Transmission Electron Microscopy Laboratory (Molecular Architecture)
- Materials Characterization Laboratory (Molecular Architecture)
- Theory Center (Origins)
- Research Greenhouse (Life)
- Biomolecular Characterization Facility (Life)
- Center for Advanced Biological Imaging (Life)
- Genomic, Proteomic, and Metabolic Laboratory (Life)
- Partnership in large telescope facility (Origins)

Crosscutting Initiatives

This plan proposes a variety of new initiatives that will support faculty and students across the six themes that have been outlined above.

- **Interdisciplinary Hires Program**—We will support and foster interdisciplinary research by hiring an exceptional interdisciplinary faculty member each year who is nominated by at least two departments.

- **Columbia Fellows Program**—By endowing 10 postdoctoral fellowships, Columbia will be able to attract top recent PhDs across a wide range of fields, strengthening the University's research productivity and scientific reputation. It will also allow us to cultivate talented and diverse developing scholars and, in some cases, identify outstanding junior faculty candidates.

- **Columbia Graduate Fellows Program**—Over the next decade the natural sciences will endow fellowships for 10 percent of its graduate students. This will allow Columbia to attract the best and most diverse group of students, many of whom receive multiple, competitive offers, and to leverage federal funding of our faculty, increasing our research competitiveness.

- **Columbia Undergraduate Research Fellowships**—In collaboration with Columbia College, this plan will endow 100 undergraduate summer laboratory research fellowships as an initial step toward providing opportunities for all students interested in participating in research as part of their undergraduate experience.

- **Laboratory Research Support Program**—This plan maintains our successful program for allocating funds to moderate-sized repairs and upgrades to laboratories through a competitive process.

- **Support for Shared Research Computing**—Following recommendations of the Shared Research Computing Task Force, we will offer support to all of our researchers with significant computing needs.

- **Bridge to PhD Program**—By offering up to two years of full-time, paid research experience and mentoring at Columbia, we will prepare students from underrepresented groups to participate in natural sciences PhD programs.

Conceptual rendering of the Center for Theoretical Physics. The strategic plan includes improving key departmental spaces: new laboratories, shared spaces for theoretical and computational work, and interactive spaces for graduate students.



IMPACT

For more than a century, the fundamental scientific research carried out in the nine natural science departments has been a driving force behind understanding our world and ourselves. The implementation of the strategic plan will strengthen Columbia science, Columbia University, and our impact on the world at large.

- **Achieve Preeminence in Science Research**—The strategies outlined in this plan will help assure Columbia's place among the top ten, and in many cases top five, universities in all fields of the natural sciences.

- **Enhance Research Competitiveness**—By attracting the best faculty, postdoctoral researchers, and students and then supplying them with sufficient administrative support and outstanding research facilities designed to encourage collaboration, Columbia will be well positioned to compete for increasingly scarce federal research funding.

- **Increase Opportunities for Undergraduates**—Through outstanding faculty, and new centers, institutes, and facilities that support interdisciplinary collaborations, as well as programs that offer substantial support for 100 additional undergraduate research fellowships, we will provide opportunities for outstanding undergraduate research in virtually any field of interest to our younger students.

- **Increase Diversity**—This plan increases diversity in the sciences by fostering the success of students from underrepresented groups interested in science at all stages of their academic careers. We will accomplish this through our Undergraduate Research Fellowships, Bridge to PhD Program, Graduate Fellowship Program, and Postdoctoral Fellows Program. We have opportunities to diversify our faculty through the New Interdisciplinary Hires Program and as we fill the numerous open and new positions within the departments.

- **Strengthen Collaborative Partnerships**—Columbia's superior social science and humanities departments and professional schools are a remarkable community in which to consider the impact of new scientific discoveries and inventions on society. Strengthening the relationship between science departments and other academic fields fortifies the entire University.

- **Enhance Public Outreach and Education**—This plan supports our faculty's continued interaction with the public though outreach to schools, institutions,

and media outlets, as well as through enrichment programs. Faculty are encouraged to make their research—which occurs everywhere from African savannahs, Brazilian rainforests, and Antarctic ice, to deep mines, the stratosphere, and space—accessible to the public through blogs, webcams, and social media.

- **Strengthen Technology Transfer and Commercial Partnerships—**Discoveries by Columbia scientists impact the electronics industry, medical diagnostics, new treatments for cancer and gene therapies, alternative energy, and national security, priming the University for partnerships with New York City and State, local companies, and industry laboratories.

- **Contribute Solutions to Today's Problems—** Columbia's research helps solve some of the world's most dire and intractable problems through discoveries about climate, energy, and the environment, new medical and diagnostic treatments, and the invention of new materials. These make the University an epicenter of new ideas and solutions to today's big questions.

NEXT STEPS

This plan will be implemented in three phases over the next decade. The first phase provides seed funding to centers that will lay the groundwork for the three new institutes and includes targeted hires in several key fields. The second and third phases prioritize the investments as efficiently and cost effectively as possible in order to meet our academic goals.

This strategic plan shows a dedicated path toward achieving an ambitious long-term vision for our nine science departments over ten years. With the appropriate investment, Columbia's nine basic science departments will achieve preeminent stature, increase research productivity, and create new educational opportunities. Recognizing our historical greatness in science, from understanding the tiniest building blocks of matter and life to answering questions about the vast cosmos, this plan outlines a way to sustain Columbia's legacy and carry us forward as scientific leaders into the next century.

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