REPORT
TASK FORCE ON THE NATURAL SCIENCES
LARS HEDIN, DECEMBER 21, 2015

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Abbreviations used in the text:

CEE, Dept. of Civil and Environmental Engineering
CHM, Dept. of Chemistry
EEB, Dept. of Ecology & Evolutionary Biology
ENG, Dept. of English
GEO, Dept. of Geosciences
MAT, Dept. of Mathematics
MOL, Dept. of Molecular Biology
PHY, Dept. of Physics
PSY, Dept. of Psychology

AOS, Program in Atmospheric and Oceanic Sciences
CHV, Center for Human Values
EEWR, Program in Environmental Engineering and Water Resources
ENV, Certificate Program in Environmental Studies
GFDL, Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration
LSI, Lewis-Sigler Institute for Integrative Genomics
PCTS, Princeton Center for Theoretical Science
PEI, Princeton Environmental Institute
PICSciE, Princeton Institute for Computational Science and Engineering
PNI, Princeton Neuroscience Institute
STEP, Program in Science, Technology and Environmental Policy
STEM, Science, Technology, Engineering, and Mathematics
WWS, Woodrow Wilson School of Public and International Affairs

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1. The Committee Charge:

This task force committee was convened by President Chris Eisgruber to "*…assess the University's strengths and challenges in the natural sciences, and to comment on how best the University can support current fields and seize emerging opportunities.*" The committee consisted of faculty members across all departments of the natural sciences. It met regularly over the 2014-15 academic year, and in the early part of the 2015-16 academic year, to discuss the future vision for the natural sciences at Princeton, to analyze data and trends, and to evaluate testimony from members of the faculty and administration (*Appendix 1*).

2. The Natural Sciences at Princeton University:

The natural sciences are central to the broader mission of Princeton University, and to Princeton's leadership among educational and research institutions worldwide. Princeton scientists have a long track record as pioneers in our quest to understand the natural world, and in the application of such knowledge to solve the most vexing problems of our time. Faculty members across the natural sciences are also deeply committed to the University's mission of educating the next generation of leading scientists, scholars, policy-makers and well-informed citizens.

Princeton has maintained exceptional and innovative leadership in the natural sciences over a period in which science has emerged as one of the most important and rapidly evolving forces of modern life. The sustained nature of this leadership is perhaps remarkable given the small size of Princeton's natural sciences compared to peer institutions (which are housed in larger-sized institutions and/or affiliated with medical schools).

Several factors have contributed to Princeton's unique leadership. First, Princeton has crafted an unparalleled niche of excellence by historically focusing on the theories and concepts that reside at the forefront of scientific progress, and by combining this focus with possession of a strong capacity for mathematical and computational analyses. This combination has placed Princeton as an exceptionally rare institution, where theoretical, computational and experimental analyses of the natural world meet in the most integrative and innovative manner.

Second, the natural sciences have collectively embraced Princeton's distinctive model for liberal arts education, by developing close, thoughtful, and highly personalized interactions among undergraduate students, graduate students and the faculty missions of teaching and research.

Third, uncommon advantages arise from the small size of Princeton as a whole, and the small size of each of the departments that make up the natural sciences. Perhaps most important is the ease by which faculty interact across research groups, combined with the existence of a university-wide culture that promotes interaction and collaboration across departments and disciplines. As a result, the natural sciences at Princeton hold the exceptional ability to rapidly respond to the emergence of new research opportunities and fields, and to nimbly and fluidly create novel positions of intellectual leadership.

Fourth, the University has historically recognized the importance of bold and judicious investments for securing leadership in emerging research fields, and for promoting novel teaching models. These investments have not only brought an enhanced capacity to the University research and teaching missions beyond that of individual research groups, but have facilitated new and imaginative interactions across fields or disciplines that have traditionally remained distinct. This ability to promote and re-shape interactions across emerging fields and disciplines is a hallmark that has served to maintain Princeton's unique position among peer institutions worldwide.

Recent investments include the Lewis-Sigler Institute for Integrative Genomics (LSI), which has positioned Princeton as a leader in the rapidly emerging field of genomics, by promoting innovative faculty interactions across historically distinct fields: genetics and molecular biology, biophysics, computation, and ecology and evolutionary biology. The Princeton Neuroscience Institute (PNI) similarly has brought together diverse faculty from the sciences and engineering, to address one of the greatest modern-day challenges: how the brain gives rise to mental processes and human behavior. The Princeton Center for Theoretical Science (PCTS) functions as a creative nexus for pioneering theory-based research and education in the natural sciences, and supports innovative interactions among faculty in physics, astrophysics, chemistry, and biology. In all three cases, bold and thoughtful investment has not only brought new resources to grand research challenges, but also allowed for the emergence of new constellations of faculty collaborations across disciplines and intellectual perspectives.

Other recent investments have improved the physical infrastructure that supports the natural sciences. The Frick Chemistry Laboratory has made possible sharply enhanced research and teaching capacities in the Department of Chemistry. The Peretsman Scully Hall has done the same for the Dept. of Psychology (PSY), and the co-location with PNI has physically brought together two fields that reside at the center of the emerging new synthesis of neuroscience and human behavior. These new buildings, together with the Carl Icahn Laboratory (home of the LSI), are starting to define a new physical neighborhood for the natural sciences on Princeton's campus.

3. The Natural Sciences Today:

Princeton's natural sciences are in a strong position today, but face challenges in being able to fully exploit the exciting opportunities now on the scientific horizon. The natural science departments are at the center of Princeton's mission to understand the natural world, and are critical to Princeton's commitment to solve societal problems that reach broadly into allied fields that include public policy, the social sciences, technology and engineering, and the humanities. World-class faculty members continue to be attracted to Princeton's culture of excellence and innovation, the ease by which novel interactions bridge boundaries, and the University's ability to nourish emerging areas of inquiry.

Students come to Princeton either with deep interests in becoming part of the next generation of leading scientists, or with a basic need to understand how science will influence their future lives. Moreover, since Princeton alumni often achieve positions of influence, either in business or political arenas, it is a responsibility of the university to instill scientific literacy and respect for evidence-based assertions as a fundamental component of the Princeton education.

Princeton is well-positioned to maintain and expand its standing as a leader in both research and education across the natural sciences. There is long-standing excellence in the fields that have served as the historical foundation for the natural sciences, with particular strength in mathematics and physics. Leadership in today's natural sciences increasingly depends on novel synthesis across traditional boundaries of study, and on new ways to abstract nature as a complex system of causal interactions. Princeton's unique niche of fostering synthesis across disciplines and the nimble integration of theory, computation and experiments will only increase in importance as the natural sciences evolve in new and unexpected ways over the next decade. In addition, the use of highly personalized and hands-on educational methods will increasingly distinguish Princeton's educational model from models based on large classrooms, massive open online courses, and more distant and/or abstract interactions between students and faculty members.

Princeton's natural sciences also benefit from close interactions with other divisions and units across the university. First, there are strong interactions and collaborations with colleagues in the School of Engineering and Applied Science, and the two divisions form a continuum of strength that spans from the basic sciences to technology solutions. Second, the natural sciences have an excellent relationship with the Woodrow Wilson School of Public and International Affairs (WWS) with focus on the science-policy interface. This collaboration is supported by jointly hired faculty members between departments and WWS, and is supported by the Program in Science, Technology and Environmental Policy (STEP, housed in WWS). Third, interactions with the social sciences and the humanities are growing, with notably strong links to the Center for Human Values (CHV), the department of History, and the emerging field of the environmental humanities.

The future of Princeton's leadership in the natural sciences is not without challenges, however. Perhaps most fundamental is the need to continuously rethink and renew the intellectual dimensions, and the interactions among faculty members, that have historically defined Princeton's ability to excel and innovate. Equally important is the need to renew physical infrastructure for research and teaching, and to invest in the scientific tools and the computational infrastructure that will ensure Princeton's leadership in both traditional and emerging fields across the natural sciences.

Central to these challenges are scientific areas in which more than ever progress depends on the investment in infrastructure, tools, or intellectual interactions at a scale greater than what can be delivered by individual faculty groups or by individual departments. This condition often defines newly emerging research fields, in which innovation arises from new interactions or new synthesis across traditional boundaries of intellectual thought, often combined with new tools, techniques, or computational abilities. While Princeton's culture of interdisciplinary interactions gives it uncommon agility to respond to such emerging opportunities, the quality of the response may also depend on specific resource investments designed to allow, promote and/or re-configure interactions among new intellectual groupings of faculty members or across departments.

Princeton's ability to lead in the natural sciences also depends on both external and internal trends. First, Princeton has a long-standing tradition of leveraging its intellectual strengths in the service of broad societal problems and opportunities. Examples include the recent investments in the emerging fields of genomics and integrated neurobiology, and the role of the Princeton Environmental Institute in coordinating the growth of interests in problems of the environment. Second, the small size of the natural sciences in general, and the departments and faculty groups that define specific research areas in particular, makes Princeton vulnerable to fluctuations in external forces including changes in research funding rates, and in internal forces that include the loss of individual faculty members.

When considered together, these opportunities and challenges place the natural sciences at Princeton in a particular strategic moment. There is need to safeguard and rekindle Princeton's long-standing ability to innovate and excel despite the small size of the institution and its faculty base. There is need to renew the role of the natural sciences as an effective partner in Princeton's educational model, and in Princeton's commitment to broader social relevance. Most importantly, there is need to prioritize the areas in which bold and judicious investment will place Princeton's natural sciences in a position of innovation and leadership at the highest level over the next ten years.

4. Trends and Emerging Opportunities:

Princeton's natural sciences are influenced by trends in the evolution of science itself, in the history of resource use and infrastructure investment at Princeton, and in the societal demands for scientific knowledge, for translating science to policy, and for the education of the next generation of scholars and citizens.

a. The Environment: A major trend in the natural sciences, and across society, is the emergence of a new class of global environmental problems, for which solutions demand the understanding of Earth as a complex natural system influenced by human activities. A component of this trend is the rapid advance in our ability to understand, quantify, and predict the evolution of complex environmental systems. New theories, new technologies, and new computational tools make it possible to observe and quantify biogeochemical and biophysical processes at scales that span from local environments to the integrated global climate system. The trend defines an extraordinary intellectual opportunity, in which solutions to some of the most urgent problems that face our society and societies around the world depend on the rapid emergence of a new field of study of complex natural ecosystems within the biosphere.

In addition, global-scale phenomena – including climate change, large-scale human migrations, shifting land-use patterns, the sustainability of food supplies, and the loss of biodiversity – influence both the natural world and economic and social-political systems worldwide. This broad class of environmental problems therefore demands novel ways to integrate the natural sciences and related fields that include public policy, economics, technology and engineering, and humanistic areas of study.

Princeton students are well aware of these broad trends and opportunities, and many perceive problems of the environment as one of the most urgent issues that will face them throughout their careers and lives. Over the past decade, there has been a systematic rise in Princeton undergraduates who focus on fields that relate to the environment, a growing number of students who pursue the interdisciplinary Certificate Program in Environmental Studies (ENV), and growing interest in environmental policy and the environmental humanities. For the Department of Ecology and Evolutionary Biology (EEB), the trend has led to a 9:1 ratio of undergraduate concentrators to faculty that greatly exceeds the university average and that of any other natural science department (3:1).

Our peer institutions face the same trends among students and faculty members. Some have responded by developing new environment-themed research and educational programs within the natural sciences, while others have instituted entirely new schools or departments dedicated to environmental problems, or new institutes designed to reach across the sciences, engineering, and policy.

Princeton is well positioned to develop world-class leadership in this rapidly emerging area. Princeton possesses strong faculty research programs on problems of the environment (though groups are distributed throughout campus), and an exceptional culture that promotes broad scholarly interactions between the natural sciences and allied departments with interest in the environment across campus. Most fundamentally, the natural sciences offer the scientific foundation necessary to engage environmental problems across campus and across disciplines.

The Princeton Environmental Institute has over two decades offered university-wide leadership by promoting interdisciplinary interactions between departments and units, and by supporting the university's mission of undergraduate education. The institute has served as a nexus that has made possible the hire of a group of world-class faculty members that interact around common interests in the environment across departments. Some of these hires have been shared appointments between the Princeton Environmental Institute and individual departments, while others have been departmental appointments that nevertheless contribute to the mission of the Institute.

b. Inter- and Multi-disciplinarity: The process and intellectual scope of science has changed dramatically since World War II. The recent National Academy of Sciences report, "*Unleashing America's Research & Innovation Enterprise*" notes that today's most urgent societal challenges – responding to global climate change, feeding a growing population, and protecting biodiversity and ecosystem services – are more complex and multi-dimensional than any previous challenge. Solutions inherently require that scientists not only cooperate and exchange ideas across disciplinary boundaries within the natural sciences, but also between the natural sciences and policy, social sciences, engineering, and the humanities. Such cooperation depends on promoting regular and close interactions between groups of scientists that share a common mission from different disciplinary perspectives. This emerging model of multidisciplinary interactions poses a formidable challenge to Princeton and other leading academic research institutions: How should future investments be leveraged so as to deliver the kind of transformative interactions across disciplines that hold the greatest promise for innovation, leadership, and solutions?

One of today's most vexing scientific and societal challenges – understanding and managing how humans influence the Earth's biosphere – rests on our ability to conceptualize Earth as a complex system of interacting biological, physical, and human forces, and to subject this view to the rigor of combined mathematical, computational, and experimental analysis. Princeton has exceptional abilities in this area (discussed below). These strengths place Princeton in a unique position relative to its peers, with considerable capacity to engage some of the greatest modern-day challenges and to build a novel program that brings together diverse departments and disciplines across Princeton's broad intellectual landscape.

c. New Tools: The development of new observational and computational tools can determine trajectories of innovation, as seen in the emergence of genomics from tools of molecular biology, chemistry and biophysics, of integrated neurobiology from tools of physiology and imaging, and of a range of computational fields (astrophysics, geosciences, "big-data" analytics, and Earth-system models) from advances in research computing. The area of microscopy and image analysis is presently undergoing rapid innovation, making it possible to directly visualize, with unprecedented temporal and spatial resolution, the complex molecular machines that lie at the heart of all life processes. This ability to view the world down to the smallest biochemical and biophysical molecular interactions promises to transform the way in which we view and measure the world, with important implications for several departments and fields within the natural sciences at Princeton.

d. Computation and Big Data Analytics: Princeton has long recognized the importance of computational modeling and analysis for maintaining leadership in the natural sciences in general, and the study of complex natural systems in particular. The Princeton Institute for Computational Science and Engineering (PICSciE) serves as a central hub for state-of-the-art computation across diverse disciplines in the sciences and engineering. In the Earth sciences, additional computational capacity comes from collaborations between Princeton research groups, PICSciE, and the nearby Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration. The newly formed Center for Statistics and Machine Learning further adds new leadership in the emerging area of "big data analytics", which focuses on the analysis of very large observational datasets that are becoming available through modern technologies. In the natural sciences, examples of "big data" include the vast quantities of genomic information that are becoming available, or the large datasets that characterize how the biophysical conditions of the Earth system change over time.

e. Trends in Infrastructure: A critical determinant of the condition and trajectory of the natural sciences is the physical infrastructure that supports the intellectual enterprise that, in turn, defines Princeton's ability to innovate and lead. Creativity and novelty of interaction do not inevitably emerge from excellent hires or the addition of new research tools. Equally important is the physical structure and social function of the office areas, laboratories, and buildings that support intellectual exchanges.

Of particular importance is the ability to co-locate faculty with shared research interests in office and laboratory clusters that promote interactions and the exchange of ideas. For large initiatives that depend on integration of perspectives across disciplinary boundaries, this means bringing together faculty from different departments into a single building or unit, as done in LSI or PNI. Such physical co-location is an essential ingredient for catalyzing the novel interactions and the shared sense of mission and discovery necessary for developing new fields of inquiry.

The impact of a new building on the health and culture of a department can be easily seen in the case of the Dept. of Chemistry (CHM), which until the recent move to the New Frick Laboratory was housed in older space distributed across several poorly connected buildings. The move to New Frick has helped fuel a transformation of the department, both by helping to attract some of the best and brightest chemists from around the world to Princeton, but also by providing the flexibility to co-locate faculty groups around thematic research areas to ensure that collaboration becomes the norm rather than the exception within the department.

Today, two natural science departments – Geosciences (GEO) and EEB – occupy older buildings where faculty members and groups are disconnected or distant from each other, and where laboratory, office, meeting, and teaching spaces are limited by the historical configuration of the aged facilities. Maintaining excellence in faculty research and in teaching, even without increases in faculty size, requires modern office clusters, laboratories, and classrooms that are not currently available. In addition, hires of new faculty, with demands for modern laboratory space, can cause exceedingly expensive re-modeling projects, which, even when completed, do not create the kind of interactive configurations of space that characterize modern academic buildings. For both departments, faculty members are distributed across two separate buildings, and the lack of available new space places an absolute limit on the their ability to grow certain key programs, to take on new research challenges, or to interact within and across groups of shared interest.

f. Trends in Student Choice: The increasing emphasis on STEM (Science, Technology, Engineering, and Mathematics) education in US federal and local governments has had a major impact on the undergraduate students that apply to, and are accepted by, Princeton. First, there is a dramatic nationwide trend in which an increasing proportion of the most highly qualified high-school students are attracted to STEM fields. Second, natural science is the first choice area of study for students that apply and are admitted to Princeton. Third, within Princeton, the number of junior and senior concentrators within the natural sciences has consistently increased over time, with an especially rapid rise in the past decade and a half. As a result of these trends, departments in the natural sciences are increasingly experiencing greater numbers of concentrators, and academically better-prepared concentrators.

g. Diversity: Improving gender and ethnic diversity is one of the most difficult challenges to the natural sciences today, as it depends on cultural change within our disciplines and in society at large. At Princeton, trends differ across the departments of the natural sciences. At the faculty level, gender disparities have generally improved across the natural sciences, with the biologically-oriented departments trending closest towards equity and the physical sciences and mathematics experiencing the least change. Across all of the natural sciences, however, there has been considerably less success with respect to underrepresented minorities. These trends are largely reflected also among postdoctoral, graduate, and undergraduate students, though the trend towards gender equity tends to be strongest in the biological sciences, where it has reached roughly equal gender ratios among graduate and undergraduate students.

5. Proposed Initiatives and Priorities:

The committee considered two distinct needs within the natural sciences. First, the committee evaluated the strength of departments, based on the understanding that the overall quality of Princeton's natural sciences emerges from the excellence of individual departments. Second, the committee evaluated opportunities and needs across the natural sciences, including initiatives that would promote the development of innovative interactions and new fields of study across disciplines, or initiatives that would make available cutting edge technological advances. These two evaluations are closely linked: Investments in broader interdisciplinary initiatives depend on the existence of a foundation of excellence within traditional departments.

In addition, the committee prioritized questions about intellectual capital, with the understanding that novelty and leadership emerge primarily as a result of the quality of interactions between faculty research groups, and between faculty and students. Of particular concern and the focus of our most important recommendations were three factors that strongly influence the nature and quality of these exchanges: the quantity and quality of physical space and infrastructure, the mechanisms by which faculty interact and innovate, and the need for investment in state-of-the-art analytical and computational tools.

The committee entertained a broad range of opportunities, challenges, and needs across Princeton's natural sciences. Initially, this discussion considered a wide range of potential initiatives. Over time, however, specific themes emerged as the committee considered investments that would carry the greatest potential for innovation, transformation, and leadership. Initiatives limited to either narrow faculty interests or to single departments were dropped, as were ideas perceived as not fundamentally centered within the natural sciences.

Each priority is summarized below, with more extensive description given in *Appendix 2* (including justification and benchmarking against peers). The sequence of priorities should not be interpreted as a rank order; all priorities were strongly endorsed and viewed as deserving of support.

Priority 1: Environment-themed Building and Environmental Institute.

A Princeton investment in the area of the environment holds exceptional promise for building the capacity needed to address one of today's most urgent and formidable challenges to science, education, and global society.

Issues of the environment not only are central to the natural sciences, but also cut broadly across departments, disciplines and academic divisions. As Princeton's faculty and students are responding to the emergence of the environment as an integrating theme across campus, the natural sciences must offer the necessary leadership in the scientific principles that underpin environmental problems. The multi-faceted nature of environmental problems makes it important not only to focus within the natural sciences, but also to reach out to fields and disciplines across the university including public policy, social sciences, engineering, ethics, values, and the humanities in general. A comprehensive environmental initiative therefore ought to address two related goals: First, to strengthen interactions, research capacity, and infrastructure within the natural sciences. Second, to promote deep and thoughtful interactions between the natural sciences and allied disciplines throughout campus.

Princeton is exceptionally well positioned to develop world-class leadership in this emerging interdisciplinary area, by building upon the excellence of current research programs and upon the university-wide culture of fluid intellectual exchange across disciplines.

The Princeton Environmental Institute (PEI) was founded in 1994 in response to increased demand for research, education, and outreach in areas of the environment. Since then, PEI has established a core group of world-class faculty members who reside in different departments across campus, but who facilely interact across disciplinary boundaries. The initial faculty core was limited to the natural sciences (GEO and EEB) and engineering (Dept. of Civil and Environmental Engineering, CEE), but has grown to include strong and mature links to public policy (STEP and WWS), and, most recently, the humanities (Dept. of English, ENG).

For Princeton undergraduate students, the Certificate Program in Environmental Studies (ENV, housed within PEI) coordinates interdisciplinary education in the area of the environment. The program has been highly successful, with increasing enrollment of students from more than 20 departments across the natural sciences, engineering, social sciences, and humanities.

In addition to PEI and ENV there exist core and adjacent assets that, when combined, place Princeton in an unparalleled position relative to its peers.

In science and engineering: (i) Princeton possesses one of the strongest climate change research programs in the world, with the greatest presence in GEO but also in EEB, WWS and the School of Engineering and Applied Science; (ii) EEB's research program is top-ranked nationally with a focus on how complex ecological systems (natural and managed) respond to environmental change; (iii) The interdepartmental Program in Environmental Engineering and Water Resources (EEWR; located in CEE) is top ranked nationally, bringing together faculty members who work on hydrology and water resources from multiple disciplinary perspectives; (iv) The National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL; located adjacent to Princeton University) develops and applies the most advanced capability in the US to model the climate and the entire earth system, with a number of Princeton-GFDL research collaborations; (v) The internationally recognized joint Program in Atmospheric and Oceanic Sciences (AOS; located in GEO) offers faculty and graduate students a formal research and educational collaboration between Princeton and GFDL; (iv) An internationally leading program in disease dynamics and the environment, with strengths in Ecology and Evolutionary Biology and the Woodrow Wilson School); and (vi) The Andlinger Center for Energy and the Environment which adds exceptional capacity to address practical technology-based solutions in the area of energy and the environment.

Beyond science and engineering: (i) The Program in Science, Technology, and Environmental Policy (housed in WWS) offers a uniquely intimate link between science and public policy at the undergraduate, Masters, and PhD levels, and is based on an exceptional faculty group in environmental policy; (ii) Faculty members in the Division of Social Sciences increasingly collaborate with environmental and climate scientists, as exemplified by the recent highly successful interdisciplinary working group on Communicating Uncertainty: Science, Institutions, and Ethics in the Politics of Global Climate Change (funded by the Princeton Institute for International and Regional Studies); (iii) the Global Health Program (associated with the Woodrow Wilson School) supports interdisciplinary interactions that increasingly include problems of the environment; (iv) There are rapidly growing interactions between the humanities and the natural sciences, including the recent hire of world-class senior faculty members in the area of the environmental humanities; and iv) There are close collaborations between faculty members in the University Center for Human Values and the natural sciences, with particular focus on the areas of environmental ethics and human values.

These diverse and interacting strengths place Princeton in an exceptional position to develop a unique brand of innovation and world-class leadership in the emerging field of the environment, within the natural sciences and across the university as a whole.

The committee proposes two initiatives that, when combined, will address the needs for building capacity within the natural sciences, and for bringing together disciplines across campus.

(i) An Environment-themed Building: The emerging theme of the environment is particularly relevant to EEB and GEO. Both departments house faculty members with diverse research interests that relate to the environment, and that often span the biology-geoscience boundary. Of particular importance are research themes that bring together biological and geological/geochemical perspectives on the environment, and that share the needs for similar types of instruments and laboratory facilities.

From the perspective of physical space, EEB and GEO are the most constrained of all natural science departments. These are the only natural science departments housed in aging buildings (Eno and Gyuot halls, built in 1924 and 1909 respectively) that are incompatible with modern environmental sciences, and that are costly to renovate for modern equipment, laboratories, and office space. Because of space constraints, both departments have limited ability not only to promote intellectual exchange, but also to take on modern research questions.

A new building that can jointly house EEB and GEO therefore is of highest priority to the natural sciences. In addition to modern functional space, this building would bring two departments focused on environmental research and teaching into a single building capable of addressing both biological and geological/geochemical perspectives of similar questions. As a result, faculty members in both departments would interact more closely, with lowered physical (and, over time, intellectual) barriers, and based on shared research competence and teaching needs. A new building could also house a small group of faculty members from CEE that have close links to the natural sciences and to PEI.

One model is to co-locate faculty within small clusters, with offices, meeting rooms, and laboratories organized in manner that promotes interaction and collaboration. Such a model has proved effective in recent Princeton initiatives including the Dept. of Chemistry's new Frick Laboratory building. These interactive spaces are necessary for the development of synergies among researchers, as they support the networks of fluid interactions that characterize rapidly changing research challenges.

There are several areas of investigation in which locally shared core laboratory facilities would deliver more cost-effective access to state-of-the-art tools, greater stability of leadership and laboratory resources, and a platform for interactions between research groups. These areas include: (i) Global biogeochemistry, in which faculty members in both Ecology and Evolutionary Biology and Geosciences depend on state-of-the art analytical tools and laboratories; (ii) Earth's geologic history and climate change predictions, in which faculty share computational and modeling tools; (iii) Environmental biodiversity, in which faculty depend on tools that analyze DNA, RNA, proteins and metabolites from individual organisms, or collections of organisms, in natural environments; and (iv) Disease dynamics and the environment, in which faculty members seek to link global patterns of disease dynamics with environmental conditions.

(ii) An Environmental Institute: Of equal importance to a new building is the urgent need to promote interdisciplinary interactions within the natural sciences and between the natural sciences and growing interests in the environment across departments and disciplines campus-wide. ***Committee members unanimously agreed that a Princeton institute with a broadly conceived integrative mission would best be able to promote the needed interdisciplinary, synergistic, and cooperative interactions***.

The committee recommends that the University establish a future working group, including faculty leaders from PEI, EEB, GEO, WWS and CEE, among other areas, to give the exact configuration of such an institute—and its relationships with existing initiatives and areas of strength—considerable thought. The committee would ask the working group to pay particular attention to the nature of the intellectual interactions and the quality of space that would best benefit Princeton. Below, the committee outlines potential models for the institute and puts forth a set of guiding principles and mechanisms to advance them.

The committee favors the idea of locating the institute on the top floor of a new EEB-GEO building, which would ensure that the institute would be physically close to the two natural science departments with strongest interests and capacities in environmental-themed research and teaching.

Princeton Models: The committee considered different models for the environmental institute. First, PEI has been highly successful at coordinating strengths in the environment across campus, by bringing together faculty from different disciplines, by offering innovation funds for research and teaching on environmental problems (through the Grand Challenges Program), and by coordinating novel and interdisciplinary undergraduate education through the ENV certificate program. PEI faculty members are distributed across individual departments, with relatively limited PEI-organized personal interactions, but some postdocs are co-located within the common PEI space.

Second, the model of the LSI and PNI, and to some degree the WWS, depends upon co-location of key faculty members, based on the idea that innovation and creativity emerge from physical proximity and daily interactions between faculty members and research groups that share in the mission of interdisciplinary exchange and research. This model does not however preclude the participation of a broader – and evolving – group of faculty from departments across campus: For example, LSI houses a set of key faculty research groups, but these groups and the LSI program still interact closely with faculty across the departments of Physics (PHY), CHM, Molecular Biology (MOL), and EEB.

Third, the committee considered PCTS, which is organized around a model of faculty and postdoctoral fellows that interact closely around specific themes and projects. A group of PCTS postdoctoral fellows is housed together, and serves to integrate research ideas and projects across faculty members (who reside in individual departments). The format for interactions includes workshops and small meetings for groups that range in size and that can include leading scholars from outside Princeton. This model for interaction allows PCTS to respond rapidly to emerging ideas and research opportunities, and to bring together new constellations of faculty members, postdocs, and students, to address these in an interactive and synergistic manner.

Fourth, the Princeton Institute for International and Regional Studies (PIIRS) model extends the idea of bringing groups of Princeton faculty members together in sustained (2-3 years) interdisciplinary collaborations focused on specific topics of global importance. The collaborations are diverse in nature and include working groups, workshops, conferences, and seminars. While the PIIRS activities are designed to bring faculty physically together in interdisciplinary settings, the institute does not house any faculty members.

The Principles of Co-location and Close Interactions: As the natural sciences have grown increasingly interdisciplinary, it has become clear that innovation depends upon sustained and close interactions among scientists who hold different perspectives but share a common mission. This is particularly true for the environment, where traditional disciplinary boundaries have become fluid in response to efforts to define the true dimensions of environmental problems.

Most of Princeton's peer institutions have taken a consolidated approach, by co-locating faculty in new schools or departments of the environment. While such an approach offers the benefit of a centralized program, it creates the considerable risk of weakening links to traditional departments and disciplines at the very time when such links are most vital for providing the depth of knowledge and creativity needed to solve complex environmental problems.

A distinguishing feature of Princeton is that interdisciplinary initiatives can bring Princeton faculty, postdocs, and students physically together in new constellations, around a common mission, and in ways that enrich rather than compete with individual departments. The transformative potential of this Princeton model can be illustrated by Holger Staude, the Class of 2009 valedictorian, a two-time winner of the Shapiro Prize for Academic Excellence, and the recipient of the George B. Wood Legacy Sophomore Prize and the Class of 1939 Princeton Scholar Award. Holger was a certificate student in the Environmental Studies Program and brought his interests in air pollution to his interactions with Prof. Henry Farber, his senior thesis advisor in the Dept. of Economics. Such close interaction between an interdisciplinary program and leading scholars in traditional departments is less likely in a centralized program, where the dialogue typically remains within the program boundaries.

The committee suggests that the principles of co-location and sustained close interactions must be central to any environmental initiative. Furthermore, the principles must function in synergy – rather than competition – with the strengths of departments, schools, and environment-themed resources across campus.

The committee considered seven mechanisms that would promote these principles:

First, the institute ought to be based on the central mission of bringing together interdisciplinary research and education in the environment, within the natural sciences and between the natural sciences and the broader intellectual community across campus.

Second, the institute ought to be organized around a *core group of co-located faculty* responsible for developing, maintaining, and continuously renewing interactions across the natural sciences and across campus. Such faculty members must be hired with great care, should possess the rare ability to serve as inspirational catalysts and innovative leaders across disciplines, and ought to hold positions shared with a home department. The makeup of the core faculty group demands careful consideration, with potential links to departments across the natural sciences, the Program in Science, Technology, and Environmental Policy, the social sciences and Center for Human Values, and the humanities (including the recent hire of Prof. Robert Nixon as the Thomas A. and Currie C. Barron Family Professor in Humanities and the Environment). To attain critical mass of interaction and cross-campus leadership, the core group ought to consist of no less than six faculty members, not counting the Ecology and Evolutionary Biology and Geoscience faculty who will already be in the building.

Individual core faculty ought to be appointed typically for no more than five years to safeguard against stagnation in the institute's research and teaching missions, with the potential for re-appointment in cases of exceptional leadership. The standard expectation ought to be that faculty members join the institute to work on specific interdisciplinary questions over a 5-yr period (supported by appropriate incentives such as postdoctoral or doctoral student fellowships), after which they return to a home department. In addition, consideration should be given to establishing an advisory group of humanists and social scientists who are interested in, and knowledgeable about, environmental policy, and who would maintain liaison with the core group of natural scientists.

Third, the institute ought to have the resources and facilities to physically bring together groups of faculty, students, and postdoctoral students from different perspectives, to work on limited-time duration (2-3 yrs.) projects that address specific urgent and innovative research topics in the area of the environment. The aim would be to bring groups together in flexible new constellations that can respond (rapidly, if necessary) to emerging intellectual opportunities in areas where Princeton can offer groundbreaking leadership. Such a *rapid-response incubator model* would further benefit from the ability to include world-class leaders in the working groups, either as short-term visitors or as visiting scientists. Postdoctoral and graduate students could serve the critical function of coordinating and executing research interactions within these thematic groups, in close collaboration with faculty mentors. In addition, there is particular need that resources are available also for junior faculty members, and that the institute's vision is shaped through conversation between senior and junior faculty members. As the end result, Princeton faculty and students would interact regularly and closely, in new and continuously renewing interdisciplinary combinations, and in a manner that would create close networks between Princeton faculty groups and leading scholars worldwide.

Fourth, the committee envisions an *Environmental Fellows Program* at the postdoctoral scholar level. This program would bring young scientists with exceptional intellectual and leadership skills to Princeton, to participate as collaborating scientists and coordinators in the thematic incubator work groups. This group fellowship program would not only assure the excellence of research and intellectual interactions in the institute, but also serve to educate the next generation of visionary interdisciplinary leaders in some of the most innovative areas of environmental problems. These young scientists should be encouraged to participate in interdisciplinary working groups with social scientists and humanists while they are in residence at Princeton.

Fifth, the institute ought to possess the resources to continue the successful *Grand Challenges Program*. This program has been a central component of PEI and has offered innovation funds for research, teaching, postdoctoral training, and undergraduate internships in thematically chosen areas, and is available to faculty members across campus.

Sixth, undergraduate education in the environment ought to be integrated as a central mission of the institute, following a model similar to the successful certificate in the *Environmental Studies Program*.

Seventh, the institute ought to have *specific mechanisms to promote interactions with environmental-themed assets*. A dedicated video link and computing cluster would ensure that Princeton faculty, postdocs, and graduate and undergraduate students could interact closely with scientists and modelers at the Geophysical Fluid Dynamics Laboratory. In addition, a dedicated program around the question of how basic scientific knowledge interacts with technological solutions for specific environmental problems could form the basis for cooperative interactions between the environmental institute and The Andlinger Center for Energy and the Environment.

An Entrepreneurial Model: At heart, the principles and mechanisms outlined above define an entrepreneurial model for innovation, leadership, and rejuvenation in the area of the environment at Princeton. The model would encourage and reward innovative projects and bold interactions, with the understanding that some projects may fail while others would succeed and lead to transformational advances and world-class leadership.

Recruiting and Retaining Faculty Leadership: It is essential that any investment in the area of the environment be combined with a strategic plan for recruiting and retaining faculty of the highest caliber and with strong and interdisciplinary leadership skills.

At present, Princeton possesses an exceptional group of innovative and interdisciplinary faculty members in fields related to the environment, which, in addition to the natural sciences, includes Civil and Environmental Engineering, English, History, the Woodrow Wilson School, and the Center for Human Values. A number of these faculty members are nearing retirement, however, and the small size of individual Princeton departments makes intellectual leadership particularly sensitive to the vicissitudes of faculty constellations.

A strategic plan for how to maintain and renew excellence and leadership among Princeton faculty must therefore be one of the highest priorities in any environmental initiative.

Link to the School of Engineering and The Andlinger Center for Energy and the Environment: The committee views the strengths of the natural sciences in the area of the environment as complementary to the Andlinger center's mission in the area of engineering and technology. There is great but as yet unrealized potential for synergy and cooperation, in which the initiative proposed here would bring fundamental and intellectually broad understanding of environmental problems that complements a perspective that emphasizes applied solutions. Problems like the current water shortage in the western US urgently calls for an integrated perspective, capable of combining fundamental first-principle understanding of environment-human systems with the potential for solutions based on technology and engineering.

The area of hydrology and water resources has historically been closely linked to research and teaching activities in the natural sciences and the Princeton Environmental Institute. The research interests of some faculty members in Civil and Environmental Engineering may therefore fit well within the vision of this new environment-themed building and institute. If practical, the co-location of these faculty members within the new building ought to be explored.

Priority 2: Center for Multi-Modal Imaging of Biological Processes.

Recent rapid developments in new microscopic and image analysis methods have provided unprecedented quantitative insights into the structure of macromolecular complexes and their functional dynamics in living organisms. Future advances in molecular biology, neuroscience, biological chemistry, biophysics, systems proteomics, and biological engineering heavily rely on the development and integration of multi-modal imaging tools. Princeton has excellent existing imaging facilities scattered in different units, including in Molecular Biology (confocal microscope), the Lewis Sigler Institute (two photon laser scanning microscopy, PALM, STORM, and STED microscope), Chemistry (single molecule tracking and manipulation), the Princeton Neuroscience Institute (Confocal, multiphoton microscopy, MRI) and the PRISM Imaging Analysis Center (SEM, TEM, AFM).

An area of imaging capability that is critically important but currently lacking in Princeton is high-resolution single particle electron cryo-microscopy (cryo-EM). The recent development of new detection hardware and image analysis software has pushed cryo-EM imaging to near-atomic resolution, and may eventually replace X-ray crystallography in resolving high-resolution atomic structure of protein complexes. These technologies are likely to have an equal impact in electron tomography, which operates at the whole cell level.

Princeton is currently lacking in this key area of molecular imaging and should invest significant resources in instrumentation and to recruit new faculty members with cryo-EM expertise in order to build our strength in this area. We further note that this revolution in EM imaging is just now getting underway and we envision many additional improvements and extensions in both the microscope hardware, molecular tagging and data analysis will take place in the years ahead. Princeton is uniquely placed to be at the vanguard of these developments given the quantitative strengths of the institution. A Center for Multi-Modal Imaging of Biological Processes can be created to coordinate the development and utilization of imaging capabilities across the campus, and make them accessible for researchers from diverse disciplines.

Priority 3: Supporting Computational Science.

Large-scale computation and ``big data” are both becoming increasingly important tools in many areas of the natural sciences. One of the most important achievements of previous Princeton University investments in the natural sciences and engineering is the establishment of the Princeton Institute for Computational Science and Engineering (PICSciE). In the last decade, there has been no greater catalyst to scientific discovery on campus than through the computational tools made available to research groups through the PICSciE facilities, their expansion into the High-Performance Computing Data Center on the Forrestal Campus, and the investment in network interconnectivity across campus and to the outside world.

An on-going investment in PICSIE will be essential for staying at the forefront of computational research in the sciences. Such investment ought to be coupled with a thoughtful strategy for PICSciE to adapt and evolve as conditions of computation change, as new faculty members are hired, and as computation increasingly influence different fields (e.g., Earth structure and composition, Earth system models, evolutionary biology, and genomics). Scientific leadership and innovation will increasingly depend on data-intensive and simulation-driven analysis and predictions, across the natural sciences in general, and within the natural sciences at Princeton in particular. It is vital that Princeton responds to this growing need for support computation in the natural sciences. It is equally vital that PICSciE takes on the necessary leadership, by understanding and tracking the changing needs and opportunities for computation across all departments in the natural sciences. The current leadership group – which has important representation from the high-end users of the facilities – should adapt and evolve as these needs change, with particular attention to needs that may develop beyond the high-end users.

PICSciE also carries the important mission of educating users that are distributed across disciplines and fields, through user courses, help sessions and workshops. This educational mission will become even more important as the natural sciences increasingly depend on computation for securing leadership in both traditional and emerging fields within the natural sciences. PICSciE therefore ought to develop a strategy for how to advertise its resources and educate the next generation of users, potentially in new fields and departments.

Of further importance is the manner in which increased computational capacity is enhanced. The process by which new computers come online, current computers are maintained, and old computers are retired must be optimized to protect the integrity, security and productivity of the research that these computers support. This means that PICSciE must have the resources to continue to support the exceptional staff who maintain these computer systems, and who are distinguished by their abilities to engage faculty and researchers and their evolving software needs.

With the availability of ever-larger data sets, scientists (like researchers in the humanities, social sciences and engineering) need new techniques that go beyond traditional statistical tools. Princeton should be at the forefront of this new field of data science. This effort will require building intellectual connections across campus. Currently, these efforts are spread over several different organizations across campus, including PICSciE, the Program in Applied and Computational Mathematics, and the nascent Center for Statistics and Machine Learning, as well as different departments. The establishment of an Institute/Program for Computational Research that synthesizes these efforts, that provides an intellectual home for students interested in data science and computation, and that brings faculty together across he university would enable Princeton to be at the forefront of this growing field

Priority 4: Enhancing the Princeton Center for Theoretical Science.

The Princeton Center for Theoretical Science (PCTS) has had a successful first decade. The center, which began as the Princeton Center for Theoretical Physics, has broadened its scope and now brings together scientists from physics, geosciences, plasma physics, astrophysics, chemistry, molecular biology, material science and chemical engineering. PCTS has brought outstanding young post-doctoral scientists to Princeton where they have worked with faculty and students and developed into some of the most outstanding young leaders in their fields. Some PCTS junior fellows have stayed at Princeton and are now exceptional members of our faculty. By hosting workshops that bring world-leaders to Princeton to collaborate on some of the most timely topics in science, PCTS has increased Princeton's intellectual influence worldwide and has served as an important resource for Princeton researchers.

Other institutions are currently investing in highly ambitious similar models for intellectual collaboration, including Harvard's Center of Mathematical Sciences and Applications (combining Mathematics, Physics, Statistics and Engineering Sciences) and Caltech's Walter Burke Institute for Theoretical Physics (combining Astrophysics, Physics, Mathematics).

The committee proposes that a further broadening and expansion of PCTS would enhance its intellectual impact both inside and outside of Princeton. Of particular importance is the inclusion of mathematics and other branches of science to PCTS. Such inclusion could occur through the addition of new senior fellows and through growth in the junior fellow program; both mechanisms would contribute to PCTS's excellence and widen its impact.

Priority 5: Gravity Initiative.

Princeton has long been a center for studying general relativity, Einstein's mathematically elegant theory that describes gravity scales ranging from black holes to the visible universe. The very name "black hole" came out of John Wheeler's legendary group here at Princeton in the 1960's and Princeton has been at the forefront of cosmology for decades.

While the theory of general relativity is turning 100 this very year, we are only now appreciating its subtleties and how to probe its predictions against observations. In essence, this study is multi-disciplinary with mathematicians, physicists and astronomers exploring different problems and aspects of the theory. It is only at Princeton, however, where all three disciplines are represented and inter-connected in the respective natural science departments.

At the moment, the field of general relativity is subject to new activity and novel developments that directly depend on synergy between the different disciplines. This offers a unique opportunity for Princeton to leverage the long-standing connections between groups working on general relativity from different disciplinary perspectives. A *gravity initiative* consisting of a short-term (5-10 year) investment in graduate students, postdoctoral fellows, and visiting faculty working with Princeton scholars in mathematics, physics and astronomy, would enhance Princeton's leadership in this field. Such an investment would also likely leverage Foundation and Federal support for experimental work on general relativity, based on Princeton's investment in cosmic microwave background research (an area where Princeton has been at the forefront since its discovery 50 years ago).

6. Enhancing the Core Strengths of the Natural Sciences.

In addition to the targeted new initiatives listed above, the committee considered investments that would enhance the core strengths that are shared across all natural science departments. Princeton's mathematics and science departments rank among the world's leaders, and this leadership depends intimately upon how our core activities are managed and supported. As Princeton competes for first-rate faculty and students, it becomes increasingly important for the University to critically evaluate the need for targeted investments that can keep Princeton competitive with peer institutions.

The committee considered three core areas that deserve particular attention: attracting and retaining faculty, enhancing faculty-student research interactions, and supporting shared core facilities. The following four issues should be given careful consideration:

First, graduate students are integral to the ability of faculty members in the natural sciences to conduct innovative and groundbreaking research. Yet, graduate students in natural science departments are largely supported by external funds and therefore highly sensitive to changes in the external funding climate, and to changing themes or fads in the topics/areas supported by federal funding. It is therefore essential for Princeton's natural science research mission to (i) be based on a sustainable and predictable level of graduate student support, and (ii) be able to insulate itself from necessarily having to chase externally defined research topics or fads. A way to address this issue is to reduce graduate student tuition through scholarships for graduate students who are completing their theses (typically years 4 and 5 of graduate school). Some of our peer institutions are addressing this by growing central funds available for graduate fellowships. This would make external grant funds go further and would help in attracting and recruiting first-rate faculty members to Princeton.

Second, departments across the natural sciences host shared-use core facilities that are used not only by faculty within the department, but also across departments. This is a highly effective model for sharing state-of-the-art research tools and has helped Princeton attract and hire first-rate faculty members in competition against our peer institution. The committee urges that this model of shared core facilities should receive sufficient future support.

Third, with grant funding becoming increasingly competitive, the availability of seed funding for novel programs, matching funds, and funding for high risk projects would be a highly leveraged use of Princeton resources as these funds will likely lead to future external federal funding. A model based on innovation funds would be appropriate, but instead of holding a division-wide competition across different disciplines, it may be preferable to have department chairs recommend faculty projects to the Dean of Research.

Fourth, the most important core activity across the natural sciences is for Princeton to continue to be competitive in its efforts to retain and attract faculty. Princeton must stay competitive with efforts by its peers to make their housing support and benefits increasingly attractive, and to address individualized relocation needs. Princeton's relatively small size and its location make this core activity paramount to maintaining its scientific excellence.

7. Undergraduate, Graduate, and Postdoctoral Education:

Faculty members in the natural sciences view their research as closely linked to the University's educational missions for undergraduate and graduate students and postdoctoral scholars. It cannot be over-emphasized how important this research-education link is to the ability of faculty members to conduct research and interact across research groups and disciplinary boundaries. In addition, faculty members view their impact on the field of science, and on society, not only based on published findings but also based on their successful training of undergraduate, graduate, and postdoctoral students that become new intellectual leaders across the world.

The issue of graduate student support therefore cannot be viewed as a problem separate from that of supporting the excellence of the research mission of the natural sciences. Graduate students are the lifeblood of the research endeavor. They do most of the actual work of research and contribute immeasurably to the intellectual milieu that drives the science. They work on the most innovative topics that cross the boundaries between research groups and disciplines, and thus are essential for establishing and maintaining close interactions across research groups. Moreover, they play critical roles in undergraduate teaching and are an indispensable, and easily overlooked, component of the unique undergraduate experience at Princeton – in the natural sciences it is usually graduate students and postdoctoral scholars who provide the day-to-day practical supervision during the senior thesis.

The committee views the apparent relentless erosion of federal funds in the sciences as a threat to the sustainability of excellence in the natural sciences at Princeton – less grant money means fewer graduate students with clear implications for the mission of the University. We stress that this threat is not unique to Princeton, and that our peer institutions are beginning to address this issue in a deliberate manner. What is unique to Princeton, given the formidable resources of the institution, is our ability to tackle this problem head-on by providing broad support for the graduate program in the form of significant financial assistance in the form of tuition and stipend. Such a bold move would give Princeton a strategic advantage over all our peer institutions. Perhaps more than any other core initiative that we can imagine, this would drive the recruitment and retention of the world's top scientists and make Princeton a magnet for the best graduate students and, by extension, enrich the undergraduate experience in the natural sciences.

For undergraduate students, independent research is the keystone of the Princeton experience. This is particularly true in the sciences where students are deeply engaged in research through their senior thesis. In many departments, some students have the opportunity to begin their research work in the summer before their sophomore or junior years. These early research experiences often lead to better senior theses and higher retention rates among underrepresented groups. With Federal funding cuts, departments are finding it increasingly difficult to maintain these programs. With additional resources, these summer programs could potentially be made available not only to Princeton science students but also to underrepresented minority students from other institutions. This could be an effective way of attracting these students to Princeton and to the Natural Sciences.

Princeton attracts outstanding postdoctoral fellows. These young scholars grow tremendously during their residency at Princeton, often do superb scholarship, contribute to graduate and undergraduate education, and become the next generation of intellectual leaders at academic institutions. Institutionally, Princeton does not recognize the contribution of postdoctoral fellows to the University's education and research programs: we provide no institutional support for this group, no postdoc association, no university-wide mentorship, training or job placement programs, and do not track their progress and future success. Many of our sister institutions including Columbia, Yale, Harvard, and Stanford have set up Offices of Postdoctoral Affairs that provide some of this support. The National Science Foundation (NSF) now requires a mentorship plan as part of all grants that support postdoctoral fellows. The committee suggests that university-wide leadership on these issues would produce significant benefits at modest investment.

8. Internationalization and the Natural Sciences:

Princeton's ongoing effort to improve and expand the University's international presence is of critical importance to the natural sciences. The scientific enterprise inherently transcends national borders, and leadership in science and science-related education depends crucially upon the ability of Princeton scientist to collaborate with colleagues worldwide and to use the world as a stage to educate the next generation of leading scientists and citizens. As part of their intensive research experience, Princeton juniors and seniors often seek experiences in first-rate foreign laboratories, unique facilities (CERN or big telescopes), or unique environments (Mpala or Panama field stations). Moreover, some of the most formidable challenges to our society (*e.g.*, climate change, the rise of new infectious diseases, or feeding a growing population) are global in nature and demand that Princeton scientists interact and cooperate with colleagues worldwide. Princeton students are well aware of the international and interdependent dimensions of these challenges, and many pursue international experiences, research projects, or participate in Princeton's novel bridge-year program.

The committee evaluated three aspects of the University's internationalization efforts, which are of particular importance to leadership in the natural sciences. First, there is a need for Princeton to support the idea that science and mathematics are models for an open, barrier-free community that brings together peoples from across the world that share common intellectual interests. The global impact of Princeton scientists spans the earliest inspirations of new scholars who seek to study and overcome obstacles to be able to attend our University, to the latest stages of prominent figures on the global stage, trained or greatly influenced by the scholarly work from Princeton, and whose judgments will have a lasting impact on our future.

This means that maintenance and rejuvenation of world-class leadership in the natural sciences necessarily depends upon the ability to attract and draw upon talent and ideas at the global scale. Conversely, such leadership also depends upon communicating findings and progress of Princeton scientists to the broader world, within the academic mission as well as to locations in the world or organizations for which findings would have practical value. As a result, the committee supports Princeton's continued investment in internationalization efforts in general, and the ability of faculty and students to visit and interact with colleagues worldwide in particular.

Second, there is particular need to enhance the research-based international experiences available to Princeton's undergraduate and graduate students. Princeton has a unique opportunity to thrust students into international experiences through scientific research collaborations, involving both travel and remote communication, through our extensive network and portfolio of research projects. In addition to enhancing this ability through the provision of targeted resources for Princeton students to visit research groups worldwide, there is a need for Princeton to facilitate visits of first-rate students from leading international research groups, including the ability to house visitors on campus. Building international research teams is a two-way process: Princeton students will also gain through their interactions with visiting students and scholars working in laboratories here in Princeton, and collaborating institutions will expect such reciprocal interaction. Such an exchange-based partnership model for intellectual exchange would greatly enhance the international presence of Princeton's research and educational missions.

Third, there is a need for the University to provide effective administrative support for the growing portfolio of international research and educational opportunities. The needs of a science student interested in international experiences will differ from those in other areas and Princeton's programs should be structured to facilitate a wide range of opportunities. Across the natural sciences, however, the committee heard concerns about difficulties for the current administrative systems to support educational and research projects beyond our national borders. The committee appreciates that internationalization places new and challenging demands on administrative systems. However, rather than being viewed as exceptions, international efforts ought to be seen as inherent to the University's mission of global leadership.

9. A Future Vision of a Vibrant and Diversified Natural Sciences at Princeton:

One of the most important outcomes of this Presidential Task Force is the emergence of a common vision for the future, shared across all of Princeton's natural science departments. Committee members met regularly and, over time, came to realize that the individual departments share a common view of how the natural sciences ought to seize opportunities, address challenges, and nurture world-class leadership in the early 21st century.

This vision includes a diversified natural sciences at Princeton. While significant progress has been made in increasing the number of women in some fields of science, they remain underrepresented in others, particularly the physical sciences and mathematics. Across all of the sciences, the underrepresentation of African-American, Hispanic American and Native Americans is striking. Unfortunately, progress has been slow in increasing representation. Princeton should take a multi-prong approach: undergraduate summer research programs can encourage Princeton students to continue in the sciences and can attract promising students from other universities to Princeton, aggressive recruitment can increase the number of outstanding graduate students, post-baccalaureate programs can increase the pool of potential applicants, and university resources can aid departmental efforts to attract the most outstanding scholars from underrepresented groups. These efforts to increase diversity at Princeton are an essential part of maintaining and enhancing our strength in the sciences.

10. Proposed Initiatives on Enhancing Diversity:

The committee considered the following specific recommendations:

First, the committee supports the 2013 Report of the Trustee Ad Hoc Committee on Diversity. Of particular importance are the strategic diversity plans that each department has developed this past academic year. These plans offer initiatives and solutions tailored to the specific challenges experienced by individual departments. It is important that this effort continues as a shared mission between each department and the central administration (offices of the Provost, Dean of the Faculty, and Graduate School), and that central resources are made available.

Second, the committee suggests that Princeton's natural science departments develop a shared understanding of best practices for enhancing diversity and for supporting student interests and sense of community. Such a shared knowledge base should consider not only successes and experiences at Princeton, but also at other institutions (*e.g.*, the Meyerhoff Scholarship Program). For example, Princeton's department of Molecular Biology (MOL) has developed a particularly successful model that has enhanced underrepresented minority students at the Ph.D. level and influenced undergraduate students. In addition, many natural science faculty members see faculty-mentored undergraduate research as a particularly effective way to interact with students, and to offer a community (in the form of the research laboratory group) for students to interact with in a nuanced and supportive manner.

Third, the committee considered initiatives that address diversity from a broader and more integrative perspective. While specifics differ across departments, there is generally a need to enhance diversity across all academic levels (undergraduate students, graduate students, postdoctoral students, and faculty). Mentors and role models are of particular importance for building an inclusive culture across these different academic levels, but the pipeline of potential hires differs across departments and selection may favor applicants from narrow groups of "feeder" schools (as discussed in the 2013 Ad Hoc Committee on Diversity Report).

One way to address the pipeline issue might be to establish a Natural Science postdoctoral fellowship that would include target of opportunity resources for women and minority applicants. Such a "Princeton Natural Science Scholars" program could offer talented postdoctoral scholars a 3-4 year residence at Princeton, support by independent research funds, close interactions with groups of Princeton faculty members, and opportunities to experience different aspects of academic leadership (including teaching). Such a program would offer the following benefits: 1) Through reputation (based on resources and opportunities) the program would serve as a magnet for attracting exceptional applicants and for enhancing diversity; 2) Individual scholars would, over time, become integrated within groups of interacting faculty, graduate students, and undergraduate students; 3) At the end of their residence, scholars could either be considered for a junior faculty line at Princeton (depending on progress and department needs), or would be hired by other institutions. In either case, the program would enhance diversity across natural science departments and fields; 4) While in residence, scholars could be given opportunities and resources to interact with graduate and undergraduate students in a mentorship role.

A complementary approach that would enhance diversity is a centralized office that could provide coherent information and organization to the collection of undergraduate students that come to Princeton for summer research experiences. This program could attract underrepresented minority students from outside Princeton. The Princeton Neuroscience Institute has a successful summer internship program with an emphasis on the training of underrepresented minority students, and examples at other institutions include the Summer Undergraduate Research Fellowship (SURF) program at Caltech and the CERN (Conseil Européen pour la Recherche Nucléaire) summer program. At present, for most units in the natural sciences at Princeton, the responsibility for identifying and funding summer students rests with the PI and occasionally with the academic department. A well-funded central effort could enhance the involvement of underrepresented minorities in science, and could attract outstanding young scholars to our graduate program.

***APPENDIX 1*: Task Force Meetings and Topics of Discussion:**

- October 15, 2014: The committee's charge and format for the work.
- November 17, 2014: Emerging disciplines and areas in the natural sciences, and trend analysis of funding sources.
- November 24, 2014: The University's strengths, weaknesses and opportunities in the natural sciences, and trend analysis of: (i) undergraduate concentrators and certificates; (iii) tenured and tenure-track faculty members; and (iv) placement and success of Princeton students.
- January 5, 2015: The role of "*big data*" and *computational science* in the future natural sciences.
- January 16, 2015: Discussion of "*big data*", "*computational science"*, and emerging ideas in the natural sciences.
- February 2, 2015: "*Climate and environmental change*" as an emerging theme that links the naturals sciences to other academic divisions.
- February 23, 2015: "*Climate and environmental change*" as an emerging theme within the natural sciences.
- March 25, 2015: Discussion of the role of the natural sciences in the modern liberal arts university.
- April 8, 2015: Discussion of internationalization of the natural sciences, and outline and format for the committee report.

Testimony:

- President Chris Eisgruber: *University's strategic planning process and specific charge to the Task Force on the Natural Sciences*.
- Dean of Research Pablo Debenedetti: *Trends in sponsored research.*
- John Storey (MOL/LSI): *The role of "big data" and machine learning in the future of the natural sciences.*
- James Stone (AST, director of PICSciE): *PICSciE's role in supporting and enabling novel developments in the natural sciences.*
- Simon Levin (EEB): *Role of theories of complexity for addressing interdisciplinary questions across the natural sciences and between academic divisions.*
- Jorge Sarmiento (GEO): *Emerging role of the bio-physical interface for understanding and modeling broad interdisciplinary questions in the natural sciences.*
- Bob Keohane (WWS) and Michael Oppenheimer (WWS/GEO): *How climate and environmental change is linking the natural sciences to policy studies and the social sciences.*
- Bill Gleason (ENG): *How climate and environmental change is linking the natural sciences to the humanities.*
- President Harold Shapiro (WWS): *How the University as a whole can best respond to opportunities and challenges in the areas of climate and environmental change.*
- Danny Sigman (GEO): *Priorities for climate and environmental change within the natural sciences.*
- Steve Pacala (EEB): *Priorities for climate and environmental change within the natural sciences.*
- Bryan Grenfell (WWS/EEB): *Infectious disease and the environment.*
- Dean of Admission Janet Rapelye: *Trends in student choices between admission and selection of a concentration.'*
- Ed Turner (AST): *Internationalization of research, scholarship, and teaching.*
- François Morel (Director, Princeton Environmental Institute): *Future vision for the Princeton Environmental Institute.* Presentations at two different meetings.

***APPENDIX 2*: Benchmark comparisons of proposed priorities:**

Priority 1: Environment-themed Building and Environmental Institute.

1. *Stanford University -- Global Climate and Energy Project*
   https://gcep.stanford.edu/about/index.html

GCEP's mission is to conduct fundamental research on technologies that will permit the development of global energy systems with significantly lower greenhouse gas emissions.

85 Full-term research programs, 38 exploratory research activities, 40 institutions worldwide, 18 Stanford departments, 188 investigators, over 700 graduate and post-doctoral students.

2. *Stanford University -- Stanford Woods Institute for the Environment*
   https://woods.stanford.edu/about/overview

As the university's hub of environment and sustainability research, the Stanford Woods Institute is the go-to place for Stanford faculty, researchers and students to collaborate on environmental research. Their interdisciplinary work crosses sectors and disciplines, advancing solutions to the most critical, complex environmental and sustainability challenges. Comprises 10 percent of Stanford University's faculty and research professionals, 148 fellows and affiliated faculty. Interdisciplinary initiative across business, earth sciences, education, engineering, humanities and sciences, law and medicine.

3. *Harvard University -- Harvard University Center for the Environment*
   http://environment.harvard.edu/

The Center encourages research and education about the environment and its many interactions with human society by connecting scholars and practitioners from different disciplines and supporting research related to the environment at every level. By sponsoring symposia, public lectures, and informal student convocations, the Center connects people with an interest in the environment. 250 affiliated faculty in 8 research areas distributed among 10 schools within the university supporting programs and faculty research grants. They sponsor Environmental Fellows (post docs), undergraduate Environmental Science and Public Policy concentration, and the Ph.D. level Graduate Consortium on Energy and Environment.

4. *Columbia -- The Earth Institute*
   http://www.earth.columbia.edu/sections/view/9

Research at the Earth Institute is organized into nine themes. Climate and Society is one of them. The Columbia Climate Center integrates research from throughout the University and across disciplines to translate the best climate knowledge into practical solutions. Undergraduate programs include a major and special concentration in sustainable development, majors in the Department of Earth and Environmental Sciences, Department of Ecology, Evolution and Environmental Biology, Department of Earth and Environmental Engineering, Barnard College Department of Environmental Science, and summer field study programs. Ph.D. programs are offered in many of the same departments. They also offer certificates and master's programs that appear to be mainly policy and management oriented.

5. *Yale -- Yale Climate and Energy Institute*
   http://climate.yale.edu/about-ycei

The Institute seeks to help the world to mitigate and adapt to climate change, while satisfying its future energy needs, with practical solutions and policies that can be implemented at local, regional or global levels through interdisciplinary research and teaching. 105 affiliated faculty, 8 post docs, 5 graduate students, 13 undergraduate students. Core funding for YCEI comes from a gift intended to promote undergraduate energy studies and research on sustainable forms of energy.

6. *UCLA -- The UCLA Institute for the Environment and Sustainability (includes Center for Climate Change Solutions)*
   http://www.environment.ucla.edu/

The Center brings together experts from the natural sciences, business, law, public policy and planning, public health and medicine, and entertainment and the media to generate knowledge and provide solutions for regional and global environmental problems. The Center's mission is to educate the next generation of professional and scientific leadership committed to the health of the planet; drive interdisciplinary environment and sustainability initiatives on campus; advise businesses and policymakers on sustainability and the environment; and inform and encourage community discussion about critical environmental issues. The Institute includes 80 faculty across 24 units in the University. There are eight research centers within the institute, including the Center for Climate Change Solutions. B.S. in Environmental Science, Minor in Environmental Systems and Society, Education for Sustainable Living Program, Graduate and Doctorate Programs in Environmental Science & Engineering, D. Env.

7. *Duke -- Nicholas School of the Environment*
   http://nicholas.duke.edu/

The Nicholas School's mission is to create knowledge and global leaders of consequence for a sustainable future, preserve the world's environmental resources while adapting to a changing climate and a growing population with aspirations for rising standards of living. Basic, applied and multidisciplinary research in the relevant physical, life, and social sciences is designed to expand understanding of the Earth and its environment. More than 100 core and affiliated faculty members. The Nicholas School offers undergraduate, graduate, and doctoral degrees and several non-degree educational opportunities. It's a regular school with departments, research centers, faculty and students.

Priority 2: Center for Multi-Modal Imaging of Biological Processes.

The impact that new methods in optimal and EM imaging will have in molecular & cellular biology can hardly be overstated – we are literally entering a new age of structural biology. As independent evidence of the widely viewed importance of these new methods, many of our peer institutions around the world have already made large-scale commitments to this area. Others are sure to follow. Institutions such as Scripps, Harvard, UCSF, Rockefeller, Yale, Stanford, ETH-Zurich, Berkeley, LMB-Cambridge and the European Molecular Biology Laboratory have all made very large investments in EM instrumentation and associated faculty in recent years, a few example are given below:

1. *New York Structural Biology Center – Simons Electron Microscopy Center.*
   http://semc.nysbc.org

The Simons Electron Microscopy Center provides expertise and resources for understanding both molecular and cellular structures. Molecular structure determination is enabled by high-end transmission electron microscopes (TEMs), direct detection cameras, and computational support for single particle analysis. Cellular structure determination is enabled by tomographic reconstructions using the TEMs and a focused ion beam (FIB) scanning electron microscope (SEM).

2. *Yale – Center for Cellular and Molecular Imaging*
   http://medicine.yale.edu/ccmi/em/

Born out of an initiative to strengthen structural biology at the Yale School of Medicine, the Cryo electron microscopy facility was initially established by the Departments of Molecular Biophysics and Biochemistry and Cellular and Molecular Physiology. It has been directly supported by the Yale School of Medicine to provide Yale faculty and staff with access to state-of-the-art imaging capabilities for the structural biological complexes.

3. *UCSF – W.M. Keck Foundation Advanced Microscopy Laboratory*
   http://www.msg.ucsf.edu/em/EMNEW2/index.html

W.M. Keck Foundation Advanced Microscopy Laboratory is located at the Misson Bay Campus of the University of California at San Francisco. Housed in Genentech Hall, this state-of-the-art facility is under the direction of Professors David Agard and John Sedat. The goal is to develop, in collaboration with the optical group, an integrated approach for imaging, ranging from atomic resolution to whole cells, with emphasis on linking structural and dynamics information with biological function.

4. *European Molecular Biology Laboratory – Advanced Imaging Center*
   http://www.embl.de/services/core_facilities/index.html

The Advanced Light and EM Microscopy Center offers a collection of state-of-the-art light and EM microscopy facilities as well as associated imaging processing tools.

5. *MRC-LMB Cambridge – Advanced Microscopy Center*
   http://www2.mrc-lmb.cam.ac.uk/research/scientific-facilities-and-support-services/scientific-facilities/electron-microscopy/

The LMB has an outstanding Electron Microscopy (EM) facility, the focus being on electron cryomicroscopy (cryoEM) of unstained biological material. The LMB has five EMs available, of which four are equipped for work with frozen specimens and two have 300kV FEG electron sources. The facility's most recent acquisition was an FEI Polara microscope with energy filter, which has greatly facilitated electron cryo-tomography. Equipment for high pressure freezing and cryomicrotomy is also available, allowing cryoelectron-tomographic analysis of vitreous sections.

6. *ETH Zurich – EMEZ Microscopy Center*
   http://www.emez.ethz.ch

EMEZ is an interdisciplinary facility of ETH Zurich providing resources for scientific research of materials using dedicated electron beams. Both, man-made and natural materials, including biological specimens, are characterized on the micro- and nano scales. The strength of EMEZ is its interdisciplinarity with a pronounced competence in sample preparation for dedicated electron microscopic characterization. EMEZ operates as part of the central facilities of ETH Zurich and is located in Zurich at the ETH Hönggerberg campus.