ENGINEERING FOR A BETTER WORLD:
THE PRINCETON VISION

The School of Engineering and Applied Science (SEAS) at Princeton University will set a new standard for excellence in engineering education and research. We will achieve this ambitious goal by instilling our teaching and research with an interdisciplinary perspective and a greater understanding of the impact of technology on society. We will educate leaders and solve pressing problems. Meeting these objectives will vault SEAS to the top ranks of engineering schools.

Science and technology permeate nearly every aspect of life, yet engineering traditionally has been a field with a narrow and technical focus. As the pace of innovation accelerates and technology grows ever more complex, science and technology are becoming increasingly interdisciplinary, demanding an approach that spans multiple academic disciplines and includes a broader, non-technical perspective. Society needs leaders who are capable of incorporating both technical and non-technical considerations, whether in academia, business, government or the not-for-profit sector.

SEAS is well positioned to achieve this vision. With our small size and world-renowned faculty and students, SEAS already has set high standards in balancing cutting-edge research and first-rate teaching. Our research focuses not only on explaining fundamental principles but also on solving real-world problems. An uncommonly close connection already exists between SEAS and the larger University, which has deep strengths in the humanities, social sciences, natural sciences and public policy. Our students become leaders, not just in traditional academic disciplines but also in industry, government and many areas of public service.

We begin this plan by outlining two foundational initiatives, which focus on setting a new standard in engineering education and on fostering an environment for high-impact interdisciplinary research. The report then describes a number of focused research initiatives that address societal needs and grow out of the specific strengths of SEAS and the larger University. The plan includes specific objectives and timetables for achieving the vision and concludes by proposing metrics for measuring our success. Implementing this plan will ensure that SEAS is an outstanding competitor for research funding and a magnet for the very best faculty, staff and students. If we are successful, peers will view SEAS as a leader in realizing the full potential of engineering. Princeton’s talented students will see in engineering the means for making the world a better place.

1. Introduction

The School of Engineering and Applied Science (SEAS) at Princeton University has outstanding teaching and research capabilities in the core disciplines and well-established interdisciplinary programs. The school is part of a premier liberal arts institution with world-class departments and programs in the natural sciences, social sciences, humanities and public policy. A solid majority of bachelor of arts students at Princeton enroll in SEAS courses that introduce them to technology. Taken together, these strengths enable SEAS to educate well-rounded students who go on to become leaders not just in traditional engineering fields, but also in many areas of industry, government, finance and public service.

The unprecedented impact of engineering on every facet of life demands, however, a new paradigm for engineering in the modern world. Our vision is to educate leaders -- both within and outside of engineering -- and to conduct interdisciplinary research that truly addresses the world's needs, by providing a substantive understanding of technology and its role in society. SEAS will strengthen its connection with the University as a whole and expand its relationships with government and industry to become the best at placing engineering in its full societal context.

This approach complements and draws strength from the broader mission of Princeton with its informal motto, “In the Nation's Service and in the Service of All Nations.” In carrying out this mission, Princeton has a history of fostering teaching and research in emerging areas of inquiry where the most pressing problems cross boundaries between traditional academic departments. For example, the recently established Lewis-Sigler Institute for Integrative Genomics combines molecular biology, physics, chemistry and engineering to make sense of the information from the human genome project. Princeton's Woodrow Wilson School of Public and International Affairs brings together faculty members from economics, politics, sociology, psychology, biology, geosciences and other departments. The University Center for Human Values supports teaching and research regarding ethics and human values across many disciplines.

The bold step of immersing SEAS within the broader enterprise of the University will not only benefit the engineering school, but will greatly enhance the teaching and research opportunities for any Princeton program that seeks a greater understanding of the human condition in an age of technology.

SEAS Today

SEAS is composed of six academic departments: chemical engineering; civil and environmental engineering; computer science; electrical engineering; mechanical and aerospace engineering; and operations research and financial engineering. The newest SEAS department, operations research and financial engineering, was formed in 1999 to apply techniques of engineering to subjects ranging from financial markets to transportation systems.

SEAS also is the home of interdisciplinary programs and institutes that help integrate departments and engage other parts of the University. The Princeton Institute for the Science and Technology of Materials (PRISM), for example, combines an extraordinary breadth of research, from theoretical physics and chemistry to applied experimentation conducted in partnership with industry.

SEAS is one of the few engineering schools to have joint programs with architecture and music and is a recognized leader in addressing the public policy aspects of information technology. Princeton also has a distinguished Program in the History of Science, which is ranked among the top in the nation.

In comparison to top engineering schools (with the exception of CalTech), Princeton's School of Engineering and Applied Science is small with approximately 120 faculty, 520 graduate students and 750 undergraduates. MIT has three times the number of faculty and six times the number of students. Stanford has close to twice the number of faculty and five times the number of students. Cornell is the only Ivy League university with an engineering school ranked in the top 10 and has twice the number of faculty and five times the number of students as Princeton.

The Strategic Planning Process

We embarked on a strategic planning process in the fall of 2003. The school held a series of 11 workshops on topics ranging from broad issues of graduate and undergraduate education to specific research areas such as nanotechnology and information technology. The workshops also explored connections between engineering and biology, environmental studies, the humanities, policymaking and industry. In all, the workshops engaged more than 750 people from varied disciplines, including faculty, staff and students as well as alumni, leaders from other institutions and industry, and generated more than 250 specific recommendations. The enthusiastic and thoughtful discussions from these workshops, along with much continuing work and input from students, faculty, staff and alumni, form the basis of our vision for SEAS.

2. The Foundational Initiatives

A. Leadership in Engineering Education

The first foundational initiative of the SEAS strategic plan is to set a new standard for excellence in engineering education. We will expose students to pressing problems with solutions requiring integrative approaches across multiple disciplines. We will challenge students to explore the full societal context of technology and its applications in the real world. We will provide new educational opportunities within the established disciplines to focus on emerging fields that show great promise. And we will retain our commitment to rigor and depth within the core disciplines of engineering. Our vision for engineering education encompasses undergraduate and graduate students, and a wider audience through outreach. Beyond our core mission of educating engineers, we are committed to teaching

non-engineers about concepts in engineering and science, instilling in them a solid understanding of technology and how it affects the world.

For too long, traditional engineering education has been characterized by narrow, discipline-specific approaches and methods, an inflexible curriculum focused exclusively on educating engineers (as opposed to all students), an emphasis on individual effort rather than team projects, and little appreciation for technology's societal context. Engineering education has not generally emphasized communication and leadership skills, often hampering engineers' effectiveness in applying solutions. Engineering is perceived by the larger community to be specialized and inaccessible, and engineers are often seen as a largely homogenous group, set apart from their classmates in the humanities, social sciences and natural sciences. Given these perceptions, few women and minorities participate in engineering, and non-engineering students are rarely drawn to engineering courses.

Princeton engineering has never particularly conformed to this tradition -- our students and faculty are too well rounded for that -- making SEAS well positioned to lead a transformation of engineering education. We seek to shift the balance from disciplinary to interdisciplinary, from ivory tower to real world, from exclusively for engineers to inclusive of all students, from largely homogenous to broadly diverse and from individualistic to collaborative. By changing our own approach to engineering education, we seek to have an impact on the culture of engineering pedagogy worldwide.

If engineering is to become truly engaged in understanding and solving societal problems, its practitioners must reflect society. Increasing diversity will facilitate new approaches and ways of thinking about engineering, while strengthening the link between technology and society. We seek to create an educational environment that is relevant and appealing to a broad population and to make this education accessible to those from diverse cultural, ethnic and economic backgrounds. Our success in this regard will address the critical shortfall of women and minority graduates in academia, industry and government.

Our plan sets five specific objectives for SEAS in education:

- Achieve top five rankings for all SEAS graduate and undergraduate programs (recognizing that rankings measure excellence in both education and research).
- Increase diversity in the SEAS student body.
- Broaden interdisciplinary opportunities for SEAS students.
- Improve scientific and engineering education for non-engineers.
- Better prepare SEAS graduates for success in their careers.

SEAS will create a new entity to spearhead and focus efforts in establishing a new standard of excellence in engineering education at Princeton. The Princeton Center for Engineering and Technology Education (CETE) will support and encourage the development of new courses, pilot educational initiatives and expose students to real world experiences. CETE will help integrate consideration of the wider societal context into existing curricula, expand opportunities in cross-disciplinary fields and develop student skills in research, policy, communications, leadership and entrepreneurship. CETE will support faculty in developing

and leading new educational initiatives. In carrying out these initiatives, CETE will partner with the McGraw Center for Teaching and Learning and the Office of Career Services.

Specific steps to be pursued include:

Interdisciplinary Education and Societal Context

- Develop an innovative first-year undergraduate curriculum integrating engineering with math and physics.
- Work with departments to add AB programs as an alternative to the traditional BSE degree. The AB program will have approximately 20 percent fewer course requirements within the discipline, allowing students greater flexibility to take courses outside of SEAS. This is modeled on the successful computer science AB program.
- Create biology "tracks" in the six engineering departments. These new options will build on bio-engineering capabilities that already exist throughout SEAS, with a goal of exposing students to an emerging and important field.
- Establish new courses, programs and teaching labs related to new areas of high-impact interdisciplinary research, supporting faculty members who invest time in developing new educational offerings. One recent example of this type of initiative is PICASso, an existing center providing interdisciplinary training in computer-aided research and data analysis in areas from computer science to astrophysics to finance.
- Develop additional courses that allow non-engineers to connect engineering to their other courses and everyday life. This work will build on the several highly popular SEAS courses that engage non-scientists in learning about technology.
- Establish the SEAS Strategic Graduate Fellowship Program to enable promising graduate students to pursue interdisciplinary opportunities during their studies at Princeton. Fellowships will enable students to work outside of their adviser's labs -- perhaps in another engineering or scientific discipline, or exploring the policy, social or cultural aspects and implications of their research. Fellowships will provide one to four years of funding, relieving faculty advisers from pressure to keep the students tied to specific research grants.

Diversity

- Establish a SEAS Engineering Outreach program targeting junior high and high school students to expose all students to science and engineering early in life. The objective is to excite more talented students, particularly women and under-represented minorities, about engineering and encourage them to apply to Princeton.
- Establish closer ties with select four-year colleges and universities having significant populations of women and under-represented minorities. This program will encourage more of these often overlooked students to apply to Princeton's graduate engineering programs.

Real World Experience and Impact

- Expand SEAS visitor program to expose students to a wide range of scholars, researchers and practitioners from other universities, industry, government and non-profits. This program will draw from Princeton's many talented alumni.
- Launch the SEAS Student Entrepreneurial Initiative to encourage and facilitate students' exploring and pursuing entrepreneurial activities while at Princeton.
- Create the SEAS Summer Internships Program to help students gain more real-world experience. Expand career advising resources focused on engineering students.
- Develop optional short courses and workshops to help students improve leadership, project management and communication skills.
- Provide seed funding and administrative support for students interested in pursuing internships, fellowships in government, study abroad or field research away from Princeton.

B. An Environment for High-Impact Interdisciplinary Research

The second foundational initiative of the SEAS strategic plan is to create an environment in which high-impact interdisciplinary research germinates and thrives. This is an environment in which engineers and non-engineers -- within and outside the University -- will work together to solve world problems and create new societal and scientific opportunities. We will create a school-wide hiring process for faculty, add critical faculty and staff positions, build major new facilities and seek greatly increased research support -- all strategically targeted toward realizing this vision.

The practice of engineering is changing almost as rapidly as technology itself. The standard paradigm of researchers working in relative isolation and publishing their results in scientific journals is no longer the driving force for innovation. In this era, the most compelling problems require collaborations that cut across traditional academic departments and nearly always involve partnerships with government agencies, industry and the not-for-profit sector. The knowledge and know-how generated by these multidisciplinary collaborations often are disseminated most effectively by direct personal interactions or through the deployment of technology in industrial products and services. These new methods are particularly important for our ambitious new model of research, which draws on a greater variety of perspectives and more fully addresses society's needs.

SEAS has made significant headway in these new directions, but also faces considerable challenges. Our mechanisms for hiring, rewarding and recruiting faculty members are less effective for those who bridge disciplines. We have outgrown current office and lab space, straining the pursuit of excellence in the core disciplines and inhibiting new interdisciplinary endeavors that demand reconfigurable common spaces and costly, specialized facilities. These limitations, in turn, have hampered the ability of SEAS researchers to win major center grants and to be selected as leaders of multi-institutional consortiums.

Our plan sets four specific objectives for SEAS in high-impact research:

- Recruit and retain leading scholars and researchers who bridge traditional engineering disciplines.
- Increase the proportion of women and under-represented minorities among SEAS faculty.
- Double the amount of SEAS sponsored research funding over the next 10 years and win more large center grants.
- Strengthen collaboration with industry and increase commercialization of Princeton technology.

We will pursue strategies that generate an exceptional research environment. The visibility from our high-impact collaborations will attract top students, result in large center grants, entice leading faculty to Princeton and SEAS, and add credence to Princeton's legacy of providing service to the nation and the world.

We will promote this fertile environment with specific programs relative to people, facilities and research support:

People

- Establish a new mechanism for hiring faculty who bridge departmental boundaries. For these positions, hiring decisions will be made at the school-wide level and the recruited faculty members may have appointments in more than one department. We will seek researchers who have demonstrated great achievement and collaborative leadership.
- Promote interdisciplinary initiatives through an expanded SEAS visitor program that facilitates and supports a significant increase in the number of scholars, researchers and practitioners visiting Princeton.
- Promote diversity in gender, racial, cultural and economic backgrounds of faculty, students and staff.

Facilities

- Build a new space for operations research and financial engineering at the intersection of Olden and Williams streets.
- Plan and build two showcase facilities, the first to be well under way in five years for the new Princeton Institute for the Science and Technology of Materials.
- Provide space for multi-user, interdisciplinary laboratories that promote faculty-led initiatives and attract visitors from industry and other institutions.
- Open by February of 2005, the E-Quad Café, an inviting location that serves as a meeting ground and a catalyst for interaction.

Research Support

- Increase support, staff and infrastructure for winning and leading large-scale research initiatives and multi-institution collaborations.
- Launch an initiative to promote and support closer interactions with corporate and non-profit partners with the objective of transferring Princeton technology into products or services that improve people's lives.
- Work closely with the University's Office of Technology Licensing to promote the transfer of Princeton technology into commercial products and services.

3. Focused Research Initiatives

In addition to the two foundational initiatives, the SEAS strategic planning process identified nine focused research initiatives where Princeton has a critical mass of talent and interest. These initiatives may be loosely grouped into two categories, those that start within technical domains and those that start with a specific societal need. Regardless of their starting point, all of the research themes selected by SEAS are broadly interdisciplinary and promise to be of great benefit to society.

A. Fundamental Approaches to Emerging Technologies

The initiatives in this category are based on areas of scientific and technical endeavor that require a cross-disciplinary approach, the results of which can have broad impact on society. While the initiatives outlined here are framed around focused engineering-related domains, they have wide implications for the society at large and require the perspectives of non-engineers. It is for this reason that on-going dialogue with researchers from the humanities and the social sciences, together with those from industry and government, is essential to the successful application of technology arising from these fields.

Engineering and the Life Sciences

Topics at the intersection of engineering and the life sciences are immensely rich in new ideas and understanding that shape physical systems as well as technologies that could improve health. We will undertake a major initiative in engineering and the life sciences, combining theory, computation and experiment to probe the fundamentals of how dynamic, living systems integrate over multiple length scales, from molecules to cells, tissues to organisms, and beyond to full ecosystems. Research will include computational biology, bio- and bio-inspired materials, biological computation and biologically-inspired engineering. This initiative builds on existing Princeton engineering efforts in bioinformatics, modeling of protein structures, patterned assembly of cell-based biomaterials and medical imaging, joined with a strong Department of Molecular Biology, the Lewis-Sigler Institute for Integrative Genomics and a geographic proximity to leading pharmaceutical research laboratories.

Materials and Nanotechnology

Since prehistoric times, the ability to produce and apply new materials has had a profound impact upon the development of societies to the extent that materials technology is commonly used nomenclature to describe a civilization's stage of development. Through a merger of existing campus centers in materials science, SEAS has created the Princeton Institute for the Science and Technology of Materials (PRISM). Encouraging entrepreneurial and collective efforts in research and education, PRISM will establish itself as the premier center for study of the interface between the fields of hard materials (semiconductors, metals and ceramics) and soft materials (synthetic and natural polymers). Its programs will encompass this intersection, ranging from nanostructures to optics and photonics, in applications that directly benefit society. PRISM's research and educational programs will be integrated across the sciences and engineering, and include extensive collaboration with industry. PRISM directly benefits from the success and national visibility achieved by the Princeton Materials Institute and the Center for Photonics and Optoelectronic Materials.

Information Science and Engineering

Computing, networks and telecommunications have been driving factors in the growth of the economy, in spreading the reach and impact of information (nationally and globally) and in changing the way that people and nations interact. We will build upon existing strengths at SEAS in information sciences and engineering to take a leadership position in networking, communications and distributed applications. Princeton already leads a multi-university and industry consortium in this area called PlanetLab. We also will collaborate with the Princeton Institute for Computational Science and Engineering and the Office of Information Technology in this endeavor.

Computational and Mathematical Approaches to Understanding Systems

Complex systems such as financial markets, power grids, the Internet and disease propagation through a population have a major impact on society. We will expand our strengths in computational and mathematical approaches to understanding such systems, directing our work in applications including finance, transportation, computation, communications, materials, chemistry and biology. This effort complements and strengthens existing activities at the Bendheim Center for Finance, the Program in Applied and Computational Mathematics, the Princeton Institute for Computational Science and Engineering, the Program in Integrative Information, Computer and Application Sciences, and the certificate Program in Applications of Computing. We also will take advantage of the outstanding computational research communities at the Princeton Plasma Physics Laboratory and the Geophysical Fluid Dynamics Laboratory.

B. Responding to Societal Needs and Opportunities

Each of the initiatives in this category arise from a specific societal issue where science and engineering can be applied to solve significant problems. We recognize the importance of non-engineers in the framing of these issues, as well as in the development and

implementation of solutions. Multiple scientific and technical perspectives also are required in these collaborative efforts. We will focus resources in the following areas to build upon existing strengths and initiatives.

Urban Environment

Increasingly, populations around the world are congregating in cities, creating high-density living conditions that stress the local environment as well as the vital infrastructure needed to support urban populations. Study of the urban environment involves challenging problems in the fields of air and water quality, energy utilization, geophysical hazards and structural design. We will leverage existing SEAS strengths in hydrology, water pollution technology, environmental remote sensing, structures, materials and architecture, and collaborate with the Princeton Environmental Institute and Princeton's School of Architecture to address this complex and important topic.

Energy and a Sustainable Future

Problems related to energy and the environment have the potential to alter, adversely and irreversibly, the world in which we live. Accordingly, we will support and establish research and educational activities aimed at understanding the links between energy sources, utilization, technological development, policy and environmental degradation. This effort also will pursue engineering advancements to prevent and mitigate the negative impacts on human health and the environment. Princeton already has significant strengths in this area with the Carbon Mitigation Initiative of the Princeton Environmental Institute, work on fuel cells in chemistry and chemical engineering, advanced fuels and combustion research in mechanical and aerospace engineering, and pioneering solar technologies in electrical engineering.

Engineering for the Developing World

Academic engineering is often focused on topics and technologies of interest or within reach of only those living in advanced societies. Tremendous benefit would be gained, however, by projects in sustainable energy, building materials and small industry designed to improve the lives of people in disadvantaged and developing regions. Through the U.S.-Africa Materials Institute and ZebraNET, Princeton already has a sizeable number of faculty, students and visitors interested and working in this area. Such a program is inherently interdisciplinary, with elements of technology, policy, government and educational outreach. Hence the effort will involve the Program in Science, Technology and Environmental Policy at the Woodrow Wilson School, an international perspective through the Princeton Institute for International and Regional Studies and expertise in the design of materials and structures found within PRISM.

Privacy and Security

Ever faster and more powerful computers, coupled with easy storage of digital information, have made privacy and security leading concerns of policymakers, corporations and the

general public. We will establish a Princeton initiative devoted to understanding and applying privacy and security technologies in the real world, where every networked computer or digital device is potentially vulnerable, examining not only the technology but also the full social and human context in which it is used. This effort will draw on Princeton's existing leadership in computer science and electrical engineering, and on strengths in psychology, economics, politics, public policy, sociology and philosophy.

Engineering and Culture

The aesthetics of bridge design, digital music and computer animation are three examples that illustrate the synergistic relationship between engineering and culture. Building on our existing collaborations, including computers and music, architecture and civil engineering, multi-media and art, we will create a new focus for innovative interdisciplinary work that spans the domains of art, the humanities and engineering. Princeton's expertise in the visualization of complex data is one key opportunity to bridge engineering and the visual arts. This initiative also will benefit from Princeton's existing strengths in new scholarship examining the impact of technology on history, culture and art.

4. Evaluating Success

Clearly defined metrics of success are essential to any plan and particularly vital for ours, given the ambitious nature of the SEAS strategic vision. While some outcomes from our efforts may be difficult to measure precisely, we will assess progress in four key areas: recruitment and retention; alumni achievement; research impact; and external reputation. In a later draft, specific targets for the foundational initiatives will be outlined in appendix reports.

Recruitment and Retention

We will measure improvements in the quality and diversity of people SEAS attracts at all levels: undergraduate students, graduate students, postdoctoral fellows, staff, visitors and faculty members. As we progress toward our goals, people who share our vision for high-impact engineering in its full societal context will see Princeton as "the place to be."

Alumni Achievement

An important result of our initiatives will be the many ways in which SEAS alumni (and indeed all Princeton graduates) go on to demonstrate leadership in the arena of their choice, particularly those who enter technology-specific fields. Tracking and measuring the achievements of our alumni will be an important parameter of success. Over time, we expect the breadth and nature of their education (more than any specific technical knowledge gained) will have a significant effect on their career choices and outcomes. We will assess the influence and impact of our alumni throughout their careers, whether in academia, industry, government and the not-for profit sector, using appropriate criteria and available data for each. For instance, we will track undergraduate alumni matriculating at top graduate

programs and alumni hired as post-docs and faculty at leading universities. In industry we will track attainment of leadership positions and the creation of new ventures.

Research Impact

The primary measure of our success as a research institution ideally would be the real-world impact of our work, the problems solved, lives improved and adverse consequences avoided. While these factors are hard to quantify, certain specific metrics we will use include the level of sponsored research funding, patents, publications and industrial collaborations.

External Reputation

Given our objective of being widely recognized as one of the top schools of engineering, it is essential to evaluate ourselves based on our external reputation. While the first three types of metrics are clearly correlated with reputation, it also is useful to measure the school's standing directly. Key measures of success include the following parameters:

- rankings of SEAS academic programs and departments;
- faculty membership in the National Academy of Engineering and National Academy of Sciences;
- professional awards and honorary degrees awarded to faculty;
- faculty leadership in professional societies, journal editorships and program committees and service on corporate boards;
- publication of widely used textbooks and tools for learning and research; and
- recognition by peers of our innovations in engineering education and research.

5. Conclusion

The results of engineering research and education are changing our lives and the world around us more profoundly than ever before, bringing great benefits as well as staggering complications. And we are poised for even more dramatic advances. Yet this engine of innovation remains largely isolated from the society it is so fundamentally changing, leaving engineering ill equipped to create solutions that integrate a broad range of expertise and perspectives.

Many leading engineering schools have begun to recognize this problem. They have called for more interdisciplinary research and the education of technology-savvy leaders. They also have acknowledged the need for greater diversity among engineering faculty and students, and for connecting engineering to its societal context. Yet we believe that no other university is as well positioned to realize these goals as Princeton. We are unique in having deep strengths in the humanities, natural sciences, social sciences and public policy as the setting for a premier school of engineering. Our small size mandates and supports a high level of collaboration across departments. We are able to call on a legacy of excellence in both research and teaching and a tradition of educating students who have demonstrated leadership within their chosen sphere of activity. And we have students and alumni who remain committed to SEAS and Princeton many decades past graduation.

We recognize that we have set ambitious goals, but are convinced that we have both the responsibility and opportunity to achieve them. Our vision builds on what is best about Princeton: an uncompromising pursuit of academic excellence; a broad, humanistic view of education; and a tradition of leadership and service.