

University of Virginia

VIRGINIA 2020

Science and Technology
Commission Report

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**Further information about the Science and Technology Commission
and its activities can be found on its Website:**

<http://www.virginia.edu/virginia2020/science/science-docs1.htm>

Executive Summary

Unprecedented advances in science and engineering are changing the very character of our society and culture. Today we are presented with new and exciting opportunities to extend life, enable economic growth, revolutionize manufacturing and business, shape our democratic processes, safeguard our natural environment, enable the defense of our nation, and enrich everyday life. In the United States, much of the truly long-range, fundamental research that underlies these advances is performed in universities. Thus, university research and university education produce directly or indirectly many of the benefits our citizens enjoy.

As technology grows in importance in our daily lives, we at the University of Virginia have the responsibility—indeed the obligation—to achieve excellence in educating some of our country’s brightest young men and women about technology. As a national research university we must contribute in significant ways to the creation of knowledge, using it in turn to create world-class educational programs and improve science and technology literacy programs.

Today, we are best known for our undergraduate programs and for graduate programs in the humanities, law, and business. The most recent rankings published by the authoritative National Research Council reveal a university with doctoral programs in science and engineering ranked in the middle of the pack, with just one—physiology—among the top ten programs in its field. By contrast, four disciplines in the humanities were ranked in the top ten nationally. The more recent *U.S. News & World Report* rankings paint a similar picture (see **Appendix A**). For a leading, comprehensive university, the difference in rankings between the sciences and engineering and the humanities is both surprising and disappointing.

Our fundamental problem is that science and engineering have been meagerly supported. Programs in these fields are significantly understaffed relative to other programs here and to the science and engineering programs of our competitors. As a result of sustained underfunding, most of our programs lack excellence across the broad range of the subfields that collectively comprise a modern scientific or engineering discipline. We lack state-funded faculty lines, the start-up funding to attract outstanding scholars, and the laboratory and classroom space for them to work.

This commission found that the University has a strong, capable faculty with a demonstrable record of making significant breakthroughs despite these constraints. Our faculty is poised and motivated to take a substantial step toward excellence. The latest *U.S. News & World Report* rankings gave high marks to our graduate programs in biomedical engineering, materials science, and psychology. Recent awards from outside agencies indicate that the momentum in many areas is accelerating. External reviewers conclude that even where the University has not achieved national prominence, our faculty have been more effective at attracting outside research funds than resource and infrastructure constraints would indi-

cate. Throughout this report we describe case after case of significant achievement across the science and engineering disciplines.

Since other universities are focusing on these areas, it is urgent for the University to act strategically and rapidly. We face both great opportunities and great challenges. By coupling strong science and engineering with our already strong humanities and professional programs, UVa could emerge as one of the strongest universities in the country and be an invaluable resource for the Commonwealth.

The level of investment needed to achieve genuine excellence cannot be made in all disciplines simultaneously. Priorities must be set. Choices must be made today and into the future. The highest probability of success in building excellence is to make choices that leverage the existing strength of our institution and that focus on growth areas that our society has judged to be critical to our future. At the same time, we must make strategic investment continually across all fields of science and engineering, nurturing the fundamentals. We must develop diverse programs with the potential to emerge as areas for additional investment in the future.

Consequently, the commission has two categories of recommendations. The first includes three focused, multidisciplinary initiatives to be launched immediately. One is a *University-wide Information Initiative* to build excellence in computer and information science and engineering and to create new approaches to scholarship in the humanities and other disciplines. The second is an initiative in *Quantum and Nanoscale Science and Engineering* that will investigate the behavior of materials, macromolecules, biosystems and devices at the atomic scale. The third initiative is in *Biodifferentiation*. Researchers will study how cells and organisms acquire and maintain their characteristic form and function as well as how to apply acquired knowledge to preserving human health.

Collectively, these initiatives involve the most of the departments of science and engineering, as well as some disciplines elsewhere in the University. They will strengthen each department that chooses to be involved. At least thirty faculty have current research in each focus area, so we can field a critical mass of faculty with expertise in each area. Because we are already teaching courses related to all of these initiatives and because they are multidisciplinary and span not just departments but schools, we anticipate that the initiatives will energize, extend, and enrich our education programs. Much of the vitality and currency in our undergraduate science and engineering courses come from the faculty who bring the latest results of the laboratory into the classroom.

The second category of commission recommendations addresses fundamental elements of the science and engineering enterprise where improvement must be made between now and 2020. These recommendations provide a larger and longer-term context in which the current, and any future, initiatives are embedded. Consequently we must move forward on them in coordination with the first three recommendations.

Of critical importance is the recommendation *to provide an endowment to recruit additional excellent faculty* and to provide properly equipped laboratory space for them to work in. We also advocate a broad and sustained effort to *recruit and support higher quality graduate students*. We recommend that the University *provide seed funding to support*

emerging research directions, a recommendation that President Casteen has already begun to enact. Last, we recommend a *strengthened central strategic management as well as coordination* both horizontally and vertically in the University.

UVa has long been regarded as one of the most efficiently run institutions in the nation. We have responded to ten years of reductions in state funding by streamlining operations and allocating our resources prudently. Accordingly, to move forward we must find new sources of funding. We will seek new resources from the University's Board of Visitors. We can make a persuasive case to the state that new resources will advance critical scientific and engineering education and that investing to achieve this advance is critical to economic development in the Commonwealth. We will create a new round of competitive proposals for sponsoring federal agencies, foundations, and industry based on the focus area initiatives. And, we will seek support from individual donors.

This report is offered to the University community—students, faculty, alumni, administration, and the Board of Visitors—and to the citizens in our region and state for their consideration and discussion.

Moving science and technology at this University to the first rank will be a difficult and costly enterprise. Our peers and competitors—which include the nation's most powerful public and private universities—are currently allocating large sums for advances in science, engineering, and medicine, focusing on fields in which they already have an advantage as well as fields in which they have identified strategic opportunities. These initiatives reflect the recognition on their part that they must make a substantial investment of resources in science and engineering if they are to play a decisive role in creating the knowledge that will both define the new century and contribute to the well being of society. Our future standing as a university will be determined by the rate at which we gain strength compared to our competitor institutions.

To continue to grow and flourish as an institution and to play a leadership role in determining the future of this nation, the University of Virginia must devise a strategic plan for strengthening science and engineering, and it must make the sustained investment of new resources to achieve the goals of that plan. A capable faculty is prepared and motivated to move forward. If new resources are invested, the commission believes that the University will be able to secure its place firmly in the top tier of national universities within two decades. This strategic plan charts the course.

Recommendations for Focus Area Initiatives

Recommendation 1: Create a University-wide Information Initiative with the goals of building international leadership in computer and information science and engineering (CISE); creating CISE-catalyzed, multidisciplinary bridge programs; and developing related world-class education programs.

Recommendation 2: Establish an Institute for Quantum and Nanoscale Science and Engineering to investigate the behavior of macromolecules, materials, bio-systems, and devices with nanoscale dimensions; develop the tools and methods to control and manipulate these structures; and exploit the

quantum properties of nanosystems to enable new paradigms for scientific measurement and technological application.

Recommendation 3: Create an interdisciplinary Institute for Biodifferentiation. Its mission will be to answer the question of how cells and organisms acquire and maintain their characteristic form and function, to understand how this process goes awry in disease states, and to apply acquired knowledge to preserving human health.

Recommendations for Sustaining Long-Term Excellence

Recommendation 4: Support *strategic* new faculty appointments by providing stable, long-lived resources to fund the start-up costs of equipping and renovating associated laboratories.

Recommendation 5: Devote resources to improve the quality of graduate education at the University and attract the nation's very best graduate students.

Recommendation 6: Establish a long-lived Fund for Excellence in Science and Technology with a merit-based selection process to stimulate innovative research.

Recommendation 7: Strengthen central leadership, charge it with formulating and communicating a broadly-based strategy for science and engineering for the University, and empower it with resources to implement strategically important programs.

Introduction: Science and Engineering at the University of Virginia

Unprecedented advances in science and engineering are changing the very character of our society and our culture. Technology offers new opportunities to extend life, enable economic growth, revolutionize manufacturing and business, shape our democratic processes, safeguard our natural environment, enable the defense of our nation, and enrich everyday life. The explosion of knowledge in these fields and the impact on society and culture of new technology pose great challenges and opportunities for universities.

Advances in these fields—which include mathematics, the natural sciences, all fields of engineering, as well as medical science and medical engineering—have their origins, directly or indirectly, in the scholarship of our universities, where most fundamental long-term research is performed. Continued societal progress depends on the education of future scientists and engineers.

It also depends upon the scientific and technological literacy of the majority of society. Advances in science and technology provide options that must be evaluated sensibly by citizens—by jurors, legislators, and voters. They raise new questions for the political scientist, the bioethicist, and the business manager. They provide new tools to the artist, the literary scholar, the historian, and the architect. Today, advances in science and technology affect the conduct of education and research in every discipline taught in every university. Yesterday, to be considered educated, one had to be literate in history and literature. Today, a person is not educated unless he or she is also literate in science and technology.

It is appropriate to ask whether the University of Virginia as an institution has fulfilled the mission of research and education in science and engineering that a leading public university should. The answer, quite frankly, is “no.” Our sterling reputation as a premier, public, comprehensive university is based—to a great extent—on excellence in the humanities and graduate programs in law and business. The University is not held in comparable regard in science and engineering. According to the *U.S. News & World Report* rankings of August 2000, UVa tied for first place among public universities with the University of California at Berkeley. In its graduate engineering programs, however, it is ranked thirty-sixth, substantially lower than all other top-ten public institutions. The situation in medicine is similar: We are ranked thirtieth, far below all but one other university in the top ten.

These rankings are corroborated by the last National Research Council (NRC) ranking of graduate programs, published in 1995. The University of California at Berkeley had thirty-five disciplines ranked in the top ten, including seven in engineering, seven in the physical sciences, and seven in the social and behavioral sciences. We had none in any of these three categories. We did have five disciplines ranked in the top ten, four in the humanities and one in biological sciences, while Berkeley had ten and four respectively. (University ranking data are discussed at greater length in **Appendix A**.)

For a premier comprehensive university, the contrast between our humanities rankings and those in science and engineering are both surprising and disappointing. The fundamental

cause is that science and engineering have been meagerly supported. Despite this, in many instances our faculty in science and engineering have compiled an outstanding record of teaching and research. **Appendix B** describes just a few of the excellent programs in education and research in the various disciplines.

U.S. News & World Report ranks our graduate biomedical engineering program fifteenth in the nation, our graduate psychology program sixteenth, and our graduate materials science program twenty-first. In some areas we are competitive in winning federal funds for research. On a funding per faculty basis, chemistry faculty rank twelfth in the nation in funding from the federal government, and microbiology ranks seventh in funding from the National Institutes of Health.

These successes have been achieved in the face of obstacles. Historically, the science and engineering programs at the University have been small, both by internal and external comparisons. Measures of excellence in universities show a high correlation between department size and quality. Undersized departments lack the breadth needed to keep abreast of the expansion of knowledge; they are unable to offer the range of courses required by the best graduate students.

Analysis of NRC statistics shows that in the college, departmental faculty size in the humanities was two percent higher than average when compared to the top-twenty NRC-ranked departments, while in the sciences the faculty size was thirty-four percent less. Although we have many outstanding individual scientists, the University as a whole falls short of the critical mass needed to be among the leading institutions. This situation is aggravated by the large number of unfilled faculty lines in the college and the engineering school, where positions remain unoccupied because of a lack of sufficient funds to start up new faculty laboratories.

Space is another critical constraint. UVa does not have adequate space for existing faculty to conduct first-class research programs, and we certainly do not have the space for additional faculty. Lack of space is cited repeatedly by national agencies as a key reason why they cannot fund our research at requested levels.

We cannot shrink from our responsibility to achieve excellence in science and engineering. The University today is a public institution with a national presence. Our faculty and alumni occupy positions of leadership and responsibility in science and engineering organizations around the country and play a prominent role in formulating national policy in a host of fields. We have an obligation to the citizens of the nation and of the Commonwealth to advance research, to educate students to perform research, to educate young people to understand science and technology, and to advance economic development.

This has always been the University's mission. Thomas Jefferson believed that social and economic progress rested in part on advances in science and technology. This University was initially distinguished among its peers by an emphasis on science and the "useful arts." Of the original eight faculty, three specialized in the sciences: mathematics, natural philosophy (as physics was then called), and anatomy and medicine.

This commission concludes that our ability to realize Jefferson's vision for the entire University and to satisfy our responsibility to the nation and the Commonwealth depends significantly on the quality of our science and engineering programs, both in teaching and in research. Our success in fulfilling our mission as well as sustaining University stature will be determined by our ability to create science and engineering programs competitive with those at the best universities in the nation.

There are four questions that the University will need to deal with between now and 2020, the dawn of our third century—either by ignoring them or by taking action:

- Will the University be a respected creator of new knowledge in science and technology?
- Will it assure educational excellence for students who specialize in science and engineering?
- Will all our graduates be literate in science and technology?
- Will we capitalize on advances in information and communications technology so as to improve the delivery of education and the conduct of research?

It is urgent that we answer these questions in the affirmative. It is time to act, and to act strategically and rapidly. Other universities are taking action to address these questions. This commission believes that continued preeminence requires stronger science and engineering programs to complement our strong humanities and professional programs. By providing the means to assure this strength, UVa can become a mainstay of the nation and the Commonwealth; it will foster advances that will contribute to the well-being and economic security of our society.

The Virginia 2020 Science and Technology Commission

The goal of the Science and Technology Commission is to chart a course that will substantially increase the University's excellence and leadership in science and engineering education and scholarship well before 2020. The commission includes faculty and students, as well as representatives of other administrative offices that directly affect science and engineering such as the University of Virginia Foundation and the Office of Development. Members collectively span the natural and physical sciences housed in the Arts and Sciences; the engineering and applied science disciplines housed in the School of Engineering and Applied Sciences; and the biomedical sciences (those in which the University has a Ph.D. program) housed in the School of Medicine. The professional schools of law and business are also represented.

The scope of this commission did not include clinical health care and clinical education, except where collaboration between scientific researchers and clinicians furthers science. The disciplines addressed have extensive and fruitful relationships across the University. Directly or indirectly, the science and engineering endeavors being considered by the com-

mission affect a substantial portion of the University's faculty, administration, and students.

The commission has met biweekly for almost two years. It sponsored a two-day workshop in which deans, provosts, and faculty from other universities described the methods they used to seize the initiative in science and engineering and build excellence. We have also talked extensively with faculty, alumni, staff, and administrators. Once we determined recommendations, we sought to identify the attributes of each one and the resources that would be necessary to support them. We also asked how the necessary resources might be obtained (see list of commission members).

This report is addressed to the University community—students, faculty, alumni, administration, and the Board of Visitors—and to the citizens in our region and state. Members of the commission are prepared to work with all elements of the University to devise timetables and implementation plans for our recommendations, as appropriate.

Essentials for Advancing Science and Engineering

The commission believes that any initiative to attain excellence in science and engineering should be based on the following principles:

1. The advancement of knowledge in science and engineering increasingly requires the collaboration of *individuals and groups who span disciplines*. While this does not deny the continued importance of disciplinary research, it recognizes that multidisciplinary collaborations have become increasingly fruitful and have become themselves a significant source of disciplinary strength. The University has a classic organization of schools, each containing disciplinary departments. Encouraging multidisciplinary efforts will not only promote insightful discovery and invention, but also require us to think creatively about the organizational and physical structures that can best foster them.
2. *Both the quality of the individuals involved and their sufficient number are critical to the success of any endeavor*. UVa must place a priority on recruiting, retaining, and nurturing world-class scholars, teachers, and administrators capable of attracting colleagues of similar caliber—as well as on attracting the most talented undergraduate and graduate students. In many areas, the University must add additional high-quality faculty, as the small size of many departments in science, engineering, and medicine precludes achieving excellence.
3. Excellent research and educational programs require appropriate *research laboratory space, equipment, and teaching facilities*. Fully functioning laboratories and equipment also require technical support staff. Currently, the University's lack of sufficient and properly equipped and staffed space for research in science and engineering undermines efforts to recruit and retain faculty, to attract externally sponsored funding, and to perform research.
4. We recognize that *achieving excellence in all fields simultaneously is simply not affordable*. We believe the University must *target a select group of areas in science and engi-*

neering for world-class excellence while providing for the strategic, persistent advancement and evolution of existing programs as opportunities arise. Choices must be made carefully, assessing intrinsic intellectual merit, examining the strengths and weaknesses of existing programs, identifying potential synergies, evaluating where new knowledge will most readily be brought forth, and giving due consideration to currently available and potential funding. We need to be practical as well as visionary. At the same time, we must periodically reevaluate and make new choices if we are to keep abreast of the rapid pace of change in science and technology.

5. We believe that any focused initiatives undertaken to bolster science and engineering should be chosen to *broadly and fundamentally advance disciplines across the University.* Initiatives should build on the strength of existing faculty and their research. Resources for targeted areas of excellence must not be reallocated from productive existing programs. On the contrary, we must seek new resources to build the infrastructure, the faculty, the student populations, and the education programs on disciplinary fronts where advancement is probable.
6. We take as a premise that *excellence in research alone is necessary but not sufficient to ensure excellence in education.* We must make certain that our researchers have the incentives and the resources to bring the results of their work to the classroom, so that our students receive the best current understanding of their field, not yesterday's wisdom.
7. Our programs should *advance the well being of the citizens of the Commonwealth and nation and promote appropriate, vigorous, and prudent economic development.* Much economic growth in the Commonwealth and the nation is based on science and technology. We need to be certain that opportunities for application of research results are exploited effectively. We need also to ensure that all students are technologically literate and are equipped to participate in the new technologically-based economy. At the same time, the University must consider the effect of its choices on the Charlottesville area, emphasizing activities that involve sustainable use of local resources and that respect the character and culture of the region.

Commission Recommendations

Taken together, the commission's recommendations provide an ambitious plan for attaining world-class science and engineering at this University. Our strategy is twofold. We recommend three high-priority initiatives in areas in which we possess a competitive advantage. Coordinating activity in these areas and applying some new resources will allow us rapidly to deploy new, innovative programs in teaching and research, raising the standing of science and engineering at the University generally and jump-starting the process of advancement across the sciences and engineering. Complementing these initiatives, we recommend targeting some systemic barriers to excellence that now hamper advances in the sciences and engineering. These recommendations, too, should be acted on immediately.

We believe that, taken together, these recommendations will have a particularly beneficial effect on undergraduate education. At the very moment when knowledge in science and technology is expanding at an unprecedented rate and exerting an ever more profound influence on our society, action on these recommendations will ensure that we have the resources to provide our undergraduates with an education that will provide literacy in these areas.

Recommendations for Focus Area Initiatives

The commission's first three recommendations propose initiatives in high-potential areas in which the University has the base and the opportunity to achieve leadership if it acts rapidly before our competitors do. To guide and inform identification of these areas, the commission used the following selection criteria:

- **A focus area should be transformative.** It should have the potential to make a dramatic difference by substantially advancing knowledge and by contributing to quality of life.
- **A focus area should contribute to the University's educational mission.** The area should correlate with our efforts to provide graduate and undergraduate students with in-depth training as well as science and technology literacy.
- **A focus area should be "ripe."** The enabling knowledge and tools should be in place to support rapid advance.
- **A focus area should add value through synergistic interactions.** Building strength in one area should provide a base for advances in other areas.
- **A focus area should be in a field in which the University can attain preeminence.** The focus area should offer the potential for sustained leadership.
- **A focus area should build on existing strengths.** UVa currently should have some of the core strengths necessary to advance the chosen area. Early leadership in an area

must come from existing faculty. We may need to recruit in sub-areas in order to capitalize on other opportunities and to build balance into research and education programs.

- **A focus area should be saleable and fundable.** There should be a broad-based constituency, both within and without the University, with the resources to support initiatives in the focus area. It should be highly likely that external research funding will be available so that the research component of the focus area can become self-supporting when it matures.
- **A focus area should have an academic impact across the University.** The focus area should have application to scholarly activities in other areas besides science and engineering.
- **A focus area should complement economic and social needs.** It should have the potential to contribute to the quality of life in the region, the Commonwealth, and the nation.
- **Collectively, focus areas should be relevant to the majority of the faculty in science, engineering, and medical research.** Developing these areas should benefit the majority of the research and education programs in these areas.

While selecting multidisciplinary areas per se was not a criterion, all three selected areas span multiple classic disciplines and accordingly will have a widespread beneficial effect on many departments throughout UVa. The first three recommendations propose three focus area initiatives:

- Recommendation 1: A University-wide Information Initiative
- Recommendation 2: A Initiative in Quantum and Nanoscale Science and Engineering
- Recommendation 3: A Initiative for the study of Biodifferentiation.

These choices should not be viewed as new disciplines, but rather as dimensions along which scholarship in the classical disciplines is currently energized. Taken together, advancement in these areas will strengthen the majority of the science and engineering departments in the University.

We advocate a sustained investment for at least the next decade in these areas, with the goal that research activity in each area must become self-sustaining. Externally sponsored research funds would be increased to finance the research, excluding space construction. We anticipate that for each of these focus areas, compelling cases can be made to the legislature to fund new faculty and staff positions. The continued vitality and effectiveness of each focus area should be reevaluated periodically. Activities within a focus area may be redirected as needed, and new focus areas created as opportunities arise. Related research and education programs will naturally be absorbed into the various departments, thus strengthening them.

Recommendations for Sustaining Long-Term Excellence

We cannot achieve long-lasting excellence, however, by pursuing initiatives in these three areas alone. We must have a complementary strategy to promote overall excellence for the long-term. Our last four recommendations address this issue.

- Recommendation 4: Make key strategic faculty appointments supported by an associated investment in the renovation and equipping of their laboratories.
- Recommendation 5: Recruit and support the nation's best graduate students. This recommendation, critical to the long-term vitality of all of our science and engineering programs, will have a direct impact on the success of undergraduate education as well as on the effectiveness of our research enterprise.
- Recommendation 6: Create a Fund for Excellence in Science and Technology to nurture innovative new research activities.
- Recommendation 7: Strengthen central strategic management within the academic portion of the University, as well as coordination—both horizontally and vertically.

One important function of the organizational changes we propose is to alter the culture so that choice and change become part of the system. In particular, new focus areas should be identified as time goes on. The commission heard a number of very strong, thoughtful proposals of additional candidate focus areas that reflect the widespread strength of our faculty.

For example, the commission heard a proposal on the area of sustainable environment that could involve projects in global-scale environment change, conservation ecology, and water quality protection. Another candidate multidisciplinary area is theoretical sciences—bringing together researchers who seek to discover new theories of turbulence, complexity, and non-equilibrium systems. Other focus areas will arise. One goal in making recommendations for initiatives is to create a culture that encourages and substantively supports our faculty as they move forward with major thrusts.

The commission believes that these two companion sets of recommendations together will energize our undergraduate and graduate programs as well as advance our research agenda. They provide a strong, coherent plan to revitalize our programs in science and engineering and to ensure that the University becomes a recognized leader in the discovery and dissemination of knowledge in the new century. We believe that if initial early investment and resources are deployed in a timely manner, we can expect to have five science and engineering programs in the top-10 percentile of NRC rankings and ten programs in the top-20 percentile by 2020.

Recommendations for Focus Area Initiatives

Recommendation 1:

Focus Area in Computation and Information Science and Engineering (CISE)

Challenge and Opportunities: Excellence in CISE as an Institutional Imperative

The emergence of computation and information science and engineering (CISE) as an intellectual discipline is a hallmark of the late 20th century. The rapid advancement of knowledge in this field will exert profound intellectual and technological influence in the 21st century. Because of the central importance of CISE, both in its own right and as a catalyst for advances in other fields, any realistic vision of the University as a great institution in the future must include world-class disciplinary excellence in CISE scholarship. Today at UVA, CISE scholars can be found mainly in computer science, systems engineering, the computer engineering portion of electrical engineering, and in cognitive science, which is based in the psychology department.

CISE involves the study of logical representation of information in forms suitable for automated processing by computing and communications machinery, as well as the design of such machinery. It also includes the algorithms and software to manage and manipulate information and the application of this technology. Major research challenges include:

- design of software-based systems to make them easier to use and more dependable
- design and performance analysis of protocols for vast computer networks
- development of extraordinarily powerful, heterogeneous, distributed computer systems
- design of software architectures for ubiquitous computing
- design of database systems for handling petabytes (10^{18} bytes) of information
- “mining” of such databases for valuable information
- integration of computing with biological processes.

The transformative power of CISE is hard to overstate. CISE is unique among disciplines in its potential to catalyze major advances in all fields of study. It offers revolutionary new

concepts and tools, for conducting research in science and engineering. Of particular importance to a university that carries Thomas Jefferson's legacy is the fact that CISE can catalyze dramatic advances in nontechnical fields. Significant advances can emerge through intellectual partnerships between leading CISE and non-CISE scholars.

CISE is also enabling enormous changes in education. It is not just that information technology can be used to deliver traditional information to students more effectively. Rather, such technology changes the very nature of how people interact with information and with each other. It will transform how we teach, how we learn, and how we conceive of our educational mission.

Interdisciplinary Partnerships

Institutions can gain enormous competitive advantage by moving to the forefront of CISE in both core and multidisciplinary studies as well as in education. Nonetheless, building world-class disciplinary strength in CISE requires major effort. The market for talent is extraordinarily competitive and many universities are competing vigorously to build excellent programs in CISE. For example, Cornell has reorganized to promote the integration of first-rate scholarship in CISE and potentially all other scholarly programs. The Universities of Michigan, Washington, California at San Diego, Georgia Tech, and Florida State among others are now investing heavily to position themselves as leaders in CISE and CISE-catalyzed multidisciplinary studies.

A second challenge is to develop a viable model for building bridges between CISE and other disciplines. Merely promoting the use of off-the-shelf technology by non-CISE scholars is not a viable model. First, such technology embodies knowledge in CISE that is frequently a decade old. Second, existing tools inherently limit creative possibilities. It is the CISE scholars who have the expertise to design the new tools needed to implement new discipline paradigms.

However, in order to engage CISE scholars in multidisciplinary investigations, such partnerships have to raise fundamental research issues in CISE. Mere programming in service to others is of little interest to scholars in CISE. The challenge is to focus on multidisciplinary activities that have significant potential to advance *both* CISE and non-CISE fields.

There are many examples of such successful partnerships. Scholarship in CISE has already broadly changed the nature of scientific research. Modeling, visualization, algorithms, and high performance computers have established computing as a third paradigm of scientific inquiry, along with theory and experiment. These tools enable advancement in many areas, including modeling of astrophysical processes, climate change, and pure mathematical exploration in cryptography and coding theory.

Computational modeling will contribute to both the biological and quantum/nano initiatives. We anticipate that new collaborations involving a broader range of non-CISE fields can lead to additional advances. Tackling problems in such diverse fields as history, archi-

itecture, biology, law, English, and religious studies with CISE scholars as partners can at once transform these fields and suggest new avenues for CISE research.

We have already had positive experience with this. The Institute for Advanced Technology in the Humanities (IATH) has propelled the University to international prominence in humanities scholarship through the novel use of computing. This success was the product of the combination of collaboration between CISE experts and scholars in history and literature.

A similar possibility for fundamental work arises at the intersection of distributed computing theory and biological morphogenesis. Concepts in distributed algorithms and computer simulation have the potential to help biologists model how local interactions among cells lead to emergent properties such as the macroscopic forms of organisms. Similarly, the study of information processing in systems of cellular “machines” is suggesting new approaches to the programming of vast swarms of microscopic computers, which are soon to be realized. CISE is also a cornerstone of biological research on the human genome and proteome, as well as for the investigation of cognition and consciousness in psychology and philosophy. The study of the brain and mind should provide a crucial source of future insight for CISE scholarship.

Unfortunately, the University lacks effective institutional mechanisms to create and promote the kinds of collaborations to propel us to world-class stature in CISE and CISE-catalyzed scholarship. Although all UVa schools have activities in information technology, they are not well coordinated or based on rich interactions with CISE scholars. For example, there are no mechanisms in the School of Engineering to promote hiring of CISE faculty whose interests could support multidisciplinary collaborations with other units.

This organizational fragmentation also undermines our educational efforts. School boundaries have impeded the creation of CISE majors for students of the College of Arts & Sciences and the development of computational fluency courses. Currently, each school and department acts to optimize its own objectives and provide for its own students—as it has been asked to do. The opportunity presented by the uniquely enabling discipline of CISE now demands that we unify our curricular efforts.

The Initiative and Its Rationale

We propose creating a University-wide Information Initiative with three objectives:

- Build international leadership in computer and information science and engineering scholarship.
- Create innovative, CISE-catalyzed multidisciplinary bridge programs across the University.
- Develop world-class education programs in CISE, in computational fluency, and in CISE-catalyzed, multidisciplinary studies.

We propose creating an institute to implement this initiative that would have much the same qualities and powers as the original Shannon Center. We propose this model for a variety of reasons. As originally constituted, the Shannon Center sits outside all schools. It helped to establish our English department as one of the best in the world. We propose to employ the same techniques as were used to achieve its excellence: hiring internationally outstanding scholars, hiring more faculty than are strictly needed to support teaching obligations, paying market premium salaries, and providing the institute as a site where current and new faculty can focus on scholarship or on the creation of bridge programs.

This institute should have a director with recognized expertise in CISE and in administration, a strong commitment to achieving excellence across a range of disciplines, and the resources, authority, and responsibility to achieve initiative objectives. The University-wide scope of this recommendation demands such a structure.

The institute is primarily to be an enabling and coordinating organization. All degrees and faculty appointments (and responsibility for tenure and promotion) would remain in departments and schools. The institute would fund faculty and staff for prearranged and limited, but renewable, terms. It would foster advancement in CISE scholarship, coordinate the creation of multidisciplinary bridge programs and centers, and oversee the development of computational fluency courses so that by 2003 all undergraduates would take computational fluency courses or have the equivalent knowledge.

Over time, fifty new tenure track faculty at junior and senior levels will be required. This judgment is based on the need to increase the size of the existing CISE programs so that they can compete with the best universities in scholarship while serving significantly expanded educational roles. Some of these faculty should be selected in the areas needed for bridge programs. In addition, at least twenty technical personnel will be required, particularly to support experimental development in the bridge programs.

This Information Initiative also requires significant new and appropriately equipped space. We propose that two buildings be funded. The first would be a state-of-the-art building to house the CISE faculty with upgraded laboratory facilities. The currently proposed Information Engineering Building could be this building. Second, a building is needed to house the first ten bridge centers, several of which already exist in inadequate space. In conjunction with the Digital Academical Village project, the college plans to construct a building that in part would house precisely the kind of bridge centers that we advocate. We strongly support creation of space for the bridge centers. Such a building would reduce space pressures for many departments as faculty relocate into it.

While the Information Initiative is grounded in scholarship, it incorporates complementary education programs that will potentially touch all undergraduate students. These programs include computer fluency for all undergraduates, innovative master's degrees and minors that derive from bridge programs, as well as the undergraduate and graduate degree programs in the CISE disciplines.

Prospects for Success

Our proposal for a University-wide Information Initiative rests on two established strengths. First, it builds on substantial leadership and expertise that exists today in CISE, in such areas as distributed information system architecture, software design, system dependability, computer network protocols, computer graphics, human computer interaction, embedded and real-time computer systems, data mining, and human perception and cognition. Second, the initiative also builds on strength in CISE-catalyzed scholarship currently underway in a variety of other disciplines. The University already has three acknowledged pacesetters in this area: the Institute for the Advancement of Technology in the Humanities, the Digital History Center, and the library's E-text Center. Last year, these activities were awarded several million dollars, including awards from the Mellon Foundation and the National Endowment for the Humanities.

Within CISE, we have particular strength in high-performance, distributed computing. Researchers have designed and built an influential meta-operating system, Legion, that can harness vast computational, communications, and data storage resources on the Internet. It directs them in a coordinated, secure, fault-tolerant fashion to solve the demanding computations required for applications such as drug design, cosmological simulation, and protein structure analysis. Complementing Legion is Centurion, a University-built, high-performance computer. Centurion integrates hundreds of cutting-edge microprocessor computers with an extremely high-bandwidth switching fabric to achieve high computational performance at a much lower cost than competing architectures.

In this initiative we want to leverage our computational modeling strengths in many fields. For instance, computer designers could collaborate with UVa astronomers who model the formation of stars, planets and black holes, as well as environmental scientists who develop quantitative models of the dynamic interaction among the atmosphere, vegetation dynamics, water, land mass and energy fluxes, and changing climate.

We have significant strength in the design of reliable and secure hardware and software systems. Researchers have developed techniques to inject, simulate, and isolate faults in devices. Faculty have developed risk analysis techniques and widely recognized software tools for static and dynamic reliability modeling and analysis of complex, fault-tolerant computer-based systems.

Software design is another UVa strength. Faculty members have international reputations in safety-critical software design, formal methods, component-based software design, the secure execution of mobile code, real time and embedded software, compilers, and the economics of software design. We are leaders in studying the dependability of information systems that control the nation's infrastructures, having formed partnerships with government and industry responsible for the infrastructure for highways, rail, banking and finance, law enforcement, and water. In the areas of embedded and real-time systems, we have efforts underway in enabling technologies such as power-aware compilers, microprocessor and memory hierarchies, security and fault detection and management, and adaptive quality-of-service for hard and soft real-time systems.

MCI recently donated \$1 million to create VintLab: a network education lab now being copied in other universities. Our network research—conducted in three different departments—covers communications and signal processing, error control, compression of data, network protocols, and efficient use of satellite, terrestrial microwave, cellular and telephone channels. The University has an award to implement T-1 connectivity to the Long-Term Ecological Research site on the Virginia Eastern Shore.

Several new multidisciplinary centers are under active discussion. The first is the Center for Interactive Media. Its focus is extending access to the intellectual resources of universities to communities that largely lack such access today. The center will explore such issues as how to use new theories on computer games and narrative interfaces to create more engaging ways for people to interact with information repositories. Ongoing research in human cognition, human computer interaction, graphics, knowledge representation, input and output devices, data mining, and information retrieval give us a foundation for building a successful center.

A proposed bridge center in Cognition and Brain Science will focus on the study of human information processing and how it relates to computational-intensive, information-technology-rich environments of the future. The initial foundation for this center will come from programs in cognitive psychology (perception and functional brain imaging), systems engineering and computer science (immersive environments, vision and human-computer interfaces), and neuroscience (information storage at synapses).

A third potential center will deal with Bioinformatics and will integrate faculty from three different schools. A human Bioinformatics program will complement a partner program on plant Bioinformatics at Virginia Tech. Connections among faculty in the biochemistry department in the School Of Medicine and computer science and systems engineering departments in the engineering school is the basis for such a multidisciplinary center. That collaboration focuses on fundamental algorithms for pattern matching in large gene sequence databases, and can build on strengths in many important sub-areas such as data mining and statistics, mass-spectrographic protein analysis, epidemiology, computer graphics, large database management. Drawing these strengths together and augmenting them with a few key additional hires can move the University to prominence in Bioinformatics quite rapidly.

Recommendation 1:

Create a University-wide Information Initiative with the goals to build international leadership in computer and information science and engineering (CISE); create CISE-catalyzed, multidisciplinary bridge programs; and develop related world-class education programs.

- Develop a world-class program of scholarship in computing and information science and engineering (CISE).
- Develop world-class, multidisciplinary bridge programs between scholars in CISE and those in other disciplines that will transform practice and theory in each discipline.

- Augment existing CISE degree programs to create a balanced, complementary set of educational programs centered on computation and information technology, including:
 - A. A set of courses in computation and information literacy open to all undergraduates not majoring in CISE by 2003. Computer Science 110 and Media Studies 110 are a step in that direction.
 - B. Two new undergraduate degree programs, a Bachelor of Arts in Computer Science for undergraduates outside of the School of Engineering who will take this program as part of a double major, and a Bachelor of Science in Computer Science degree in the College of Arts & Sciences.
 - C. Innovative master's degree programs based on the scholarly work of the bridge programs and strong discipline foundations. The master's degree contemplated by the IATH and the Center for Interactive Media could be the first of such degrees.
- Create an institute on the pattern of the Shannon Center for Advanced Studies with the goal of achieving the Information Initiative.
- Establish fifty new lines for junior and senior faculty, jointly appointed in the institute and one or more existing departments.
- Allocate \$200 million to support building construction, recruitment of faculty, and development of the overall educational and research program.

Recommendation 2:

Focus Area in Quantum and Nanoscale Science and Engineering

Challenges and Opportunities

The spectacular diversity of the macroscopic biological, chemical, and physical properties of substances arises from complex interactions between a relatively small number of distinct atomic elements and their environments. Scientists and engineers have recognized for decades that nature exercises exquisite control of the composition and topology of materials at the atomic or nanometer scale. Biochemists, materials scientists, electrical engineers, physicists and basic life scientists have begun to develop methods to synthetically create nanostructures. They fine-tune the macroscopic characteristics of materials, as well as create molecular-scale devices. Some of these nanomaterials exhibit quantum effects that promise a multitude of new technologies, ranging from novel light-emitting particles to device concepts that enable quantum state entanglement for communications and computation.

Over the years, researchers have gradually increased the body of knowledge about the fundamental behavior of atoms and molecules in different environments. Today, instrumentation permits researchers to see and assemble elements at the atomic level so that they can test hypotheses and engineer new materials and devices. As a result, a new field has emerged: quantum and nanoscale science and engineering. It involves the synthesis and control of systems whose dimensions measure only a few to a few hundred atoms (that is, 1-100 nanometers). In this size regime, the properties of materials depend upon the types of atoms present, the way in which they are assembled, and the size/shape of the nanoparticle itself. As we learn how to control all of these design parameters at the atomic level, scientists are creating materials with extraordinary properties. In the life science arena, the machinery for photosynthesis and molecular motion are amazing examples of bionanotechnology. Scientists are now attempting to create similarly active, synthetic structures. Revolutionary consequences will follow.

The frontiers of research in the life sciences, biochemistry, chemical engineering, physics, chemistry, electrical engineering, chemical engineering and materials science are being transformed by nanoscale instruments, techniques, and devices. One example is quantum dots. These 10-50 nanometer diameter particles are made by colloidal chemistry. They emit intense light, whose color depends only on their size. This nanotechnology may deliver displays whose resolution exceeds that of today's best photographic processes. Another example is carbon nanotubes. Single strands of this material are only a few atoms in diameter, but can have macroscopic lengths. These nanowires have uncommon strength and novel conduction properties. In the future they may electrically connect individual atoms or nano-objects on surfaces into circuits.

Still other applications relate to the life sciences. Most proteins, peptides, and viruses are a few tens of nanometers in size and are therefore nanoscale objects. Many of the same tools used to determine structure and the mechanistic behavior of inorganic nanomaterials can also advance our understanding of the basic biochemistry of life by enabling researchers to make observations not possible before. For instance, it is now possible to tag biomolecules with quantum dots and optically track changes in a three-dimensional structure over time, say, as tissue grows. Selective protein recognition, binding, and separation are also possible.

Significant impacts for environmental sustainability can also be expected through the development of nanostructured catalysts, atomically engineered corrosion resistant materials, nanoporous filters, and new devices for efficient solar energy storage and conversion.

To provide another example of potential impact, consider the semiconductor industry that is driving inexorably toward the nanoscale region. Increased computation rates, data storage density, and electronic data transmission speeds are all forcing devices to smaller size and to more sophisticated architectures. The semiconductor industry roadmap predicts that 10 nanometer feature-sized elements will be required by 2015. Exquisite nanoscale patterning control in three dimensions will become one of the semiconductor industry's primary challenges.

Intellectual and Technological Issues

The most interesting nanoscale systems are not simply miniaturized copies of existing devices. Rather, they exploit the physics of the nanoscale to create materials with chemical and physical properties that are radically different from their macroscopic counterparts. For example, nanoscale objects have enhanced surface-to-volume ratios. They are strongly influenced by steric, electrostatic, hydrophobic, and other molecular-scale interactions, producing a range of distinct chemical and physical properties. Moreover, the smallest nanoscale systems act like artificial atoms and behave according to quantum rather than the classical laws of nature. As a result, they exhibit properties that are influenced by wave-like interference phenomena and have quantized energy levels that are size, shape, and composition dependent.

Harnessing the quantum aspects of these systems will result in new paradigms for measurement science and electronics applications. For example, advances in electronics have resulted from control of the charge and mobility of electrons. Electrons have another property that can be manipulated—spin. A new generation of devices will emerge as researchers learn how to control spin (likely using magnetism) to build artificial structures.

Another example is particularly relevant to the Virginia Information Initiative proposed earlier. Currently, computers, information storage, encryption hardware, software, and protocols are based on classical binary logic, relying on bits that can have values of 0 *or* 1. Researchers are now exploring the use of controlled quantum systems and quantum binary logic, qubits that can simultaneously have values of 0 *and* 1, for the development of quantum computers and quantum information encryption and storage. Implementation of quantum encryption schemes and computational algorithms will guarantee secure transmission of information and

enable solutions to problems too difficult to *ever* be solved on *any* computer based on classical architectures.

Because of the emergence of tools such as scanning-tunneling and atomic-force microscopy probes, as well as optical tweezers, it is now possible to move individual atoms on a surface, create synthetic structures with atomic-scale precision, and measure extremely small interparticle forces. By combining nanostructures into composites and multilayers, one can engineer devices with properties and functionality very different from the sum of the individual parts.

The Initiative and Its Rationale

We propose that the University integrate and build on its many existing strengths and create an Institute for Quantum and Nanoscale Science and Engineering under the leadership of a world-class scholar in this area. Such an institute would provide an organizational focal point for the interdisciplinary research necessary for advances in this field. The institute would be housed in newly-built space in the natural science and engineering precincts. Such new space would be designed and equipped for research and graduate instruction in quantum- and nano- materials, devices, and electronics, and for work in nanoscale biology.

We need to recruit thirty new junior and senior faculty in quantum and nanoscale science and technology to create a world-class facility. In addition, we should establish fifteen new endowed faculty chairs to provide greater incentives for attracting and retaining the best senior scientists in the area. Combined with our existing faculty, this critical mass of expertise would establish the University as one of the nation's premier facilities for nanoscale science and technology.

Although not a degree-granting organization, the institute would be an excellent resource for training future generations of scientists and engineers in this critical field as well as in the flexible research processes needed for discovery. Quantum and nanoscale science and engineering blur the boundaries between chemistry, chemical engineering, materials science, electrical engineering, physics, biomedical engineering, many aspects of the life sciences, environmental sciences, and some parts of computer science. Students actively involved in research will be trained in diverse science and engineering fields.

The facilities and resources assembled would provide support for several hundred new master's and Ph.D. students. New bachelor-level degree programs in nanoscale science and technology will be extremely attractive to high technology industry in the region and the Commonwealth.

Prospects for Success

Quantum and nanoscale science and engineering is ripe for investment. In recent testimony to Congress, Neal Lane, the President's advisor for science and technology (and the former director of the National Science Foundation) stated: "If I were asked for an area of

science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering.” The current climate for government funding in this area is very favorable, with a presidential FY2001 budget recommendation for nanoscience and technology research that is almost double that of FY2000.

The University is well positioned to take advantage of this development. The graduate program of the Department of Materials Science and Engineering is already ranked twenty-first in the nation by *U.S. News & World Report*. A large number of faculty in this department and others already participates in fields related to quantum and nanoscale science and engineering. Both theoretical and experimental work is ongoing in single-atom assembly and imaging, laser control of atoms and molecules, and spinelectronics (in chemistry, physics, and materials science). In addition, investigations of chemical synthesis and biomolecular properties at the nanoscale are currently being pursued (in chemical and in biomedical engineering) in the areas of catalysis and biomechanical adhesion.

University researchers are also experimenting with a variety of new materials such as nanoporous aerogels and bioaerogels, nanoscale polymer building blocks, strong materials, atomic clusters, biomedical thin films, and semiconducting thin films (in mechanical and aeronautical engineering, chemistry, materials science, physics, and electrical engineering). They are also exploring the properties and functionality of new devices based on nanomaterials such as vertical cavity lasers, biosensors, novel magnetic data storage media, band-gap engineered photonic crystals, qubits for quantum computation and communication, biomolecular motors, and electroactive polymers.

A number of departments have indicated a desire to hire faculty in this area. These hires will cement fragmented groups of excellent researchers around the University, forming a world-class institute for quantum and nanoscale science and engineering. For example, over the next few years the biomedical engineering department will be recruiting between two and five new faculty in related areas, as part of a Development Award from the Whitaker Foundation. Support garnered from this initiative will enable the chemistry and chemical engineering departments to extend their list of distinguished faculty, each with three new recruits in nanoscale science. These new researchers, when combined with current and new faculty in biomedical engineering will establish the University as a recognized center for nanoscale research in biological systems.

Additionally, the Department of Physics recently hired two junior faculty in quantum computing and quantum information and has been attempting to attract at least three more faculty in condensed, particularly nanoscale, systems. Linkages can be made with mathematicians in the subfields of cryptography and coding theory. Additional facilities will likely make these appointments possible, strengthening the connection to programs in electrical engineering and materials science.

Within the College of Arts & Sciences and the School of Engineering, the University has strong programs in nanostructured metals, nanoscaled semiconductors, and chemical, electronic, and optical properties of surfaces. Three or four new positions in each of these areas would produce a center of international prominence while providing remarkable collaborative opportunities.

Like nanoscale systems themselves, recruiting groups of faculty into individual departments and enabling their interaction through shared building space will create an institute whose strength and breadth are much greater than the sum of the individual units. At the atomic and nanometer scale, there are no fundamental boundaries between disciplines. The tools and techniques used to manipulate atoms, particles, and their mutual interactions are often independent of the basic science inquiry or final application. Establishing a group of researchers across disciplines that speak the same microscopic but different macroscopic languages will lead to collaborative activities that result in unprecedented and unforeseeable scientific and technological advances.

Faculty members in physics, chemistry, materials science and electrical engineering have been extraordinarily successful in obtaining highly competitive multidisciplinary program funding in nanoprinting, qubit technology, and giant magnetoresistance. In July 2000, the University won a \$5 million award to create an NSF-funded Materials Research Science and Engineering Center (MRSEC) in nanoscale materials design. Awards increased from \$5 million in FY 96 to more than \$12 million in FY 2000. It is not unreasonable to expect the proposed institute to obtain at least \$20 to \$25 million of annual research support from the federal government, foundations and industry within five years. We have complementary educational programs that include the Science and Engineering of Laser Interactions with Matter IGERT program, the NSF microelectronic program, and a large educational component of the MRSEC program.

The Virginia legislature created a research fund last year, and one of the persuasive examples of why the state should support research was a materials science center proposal similar to the newly funded MRSEC. The state government evinces a growing appreciation for the ability of world-class research infrastructure to attract new and expanded industry to the Commonwealth. We are hopeful that the potential for economic development in the nanoscale area will lead the legislature to provide new funding for the needed, additional faculty. At the national level, the University may have an additional, recognizably “unfair” advantage in this area if the first Extreme-Ultraviolet Free Electron Laser, a next-generation tool for nanoscale processing, is built in Charlottesville.

This area is transformative. The state of knowledge and capability of experimental tools are ripe for dramatic advances. The area is synergistic with basic research in all of the natural and life sciences and related fields of engineering. It is crucial that the University moves to the forefront of research in order to assure that our education programs at both the undergraduate and graduate levels are first rate. The breadth and scope of the existing competencies, combined with the demonstrated ability of faculty involved in this area to secure highly-competitive, multidisciplinary awards, indicates a potential for UVA to become a world renowned institution in quantum and nanoscale science and engineering.

Recommendation 2:

Establish an Institute for Quantum and Nanoscale Science and Engineering to investigate the behavior of macromolecules, materials, bio-systems, and devices with nanoscale dimension; develop the tools and methods to control and manipulate these structures; and exploit the quantum properties of nanosystems to enable new paradigms for scientific measurement and technological application.

- Fund with University resources a full-time director and administrative/technical staff.
- Recruit outstanding faculty in quantum and nanoscale science and engineering. Establish fifteen new endowed chairs and thirty new lines for junior and senior faculty, jointly appointed in the institute and one or more existing departments.
- Secure funds for the construction of the research and education space needed for the institute. It must include state-of-the-art, shared laboratory infrastructure for both research and instruction. Assuming approximately 1000 square foot of research space per new faculty member and 5000 square feet of offices, that equates to a pair of buildings providing at least 50,000 square feet of space.
- Secure \$25 million for institute faculty start-up and central experimental and computational facility expenses.
- In all, the University should designate approximately \$150 million to support construction of the building, recruitment of faculty, and development of the overall program.

Recommendation 3:

Focus Areas in the Integration of Form and Function in Differentiating Biological Systems: The Biodifferentiation Institute

Challenges and Opportunities

Dramatic advances during the last half-century have made it possible to define with great precision biological processes at a fine-grained level, at the realm of single cells and molecules. It is now possible to identify, isolate, and manipulate genes in order to identify their unique functions in health and disease. The recently completed sequencing of the human genome represents the scale of this scientific undertaking as well as the breathtaking advances that it promises.

One of the most exciting and important opportunities is to advance from the study of single units (such as cells and molecules) to the understanding of how cells and organisms acquire and maintain their characteristic form and function. Approaching the questions from the systems perspective (rather than from that of a single cell or molecule) will allow researchers to learn how cells integrate myriad incoming signals (physiological, mechanical, and electrical), form a coherent population, establish and maintain functional form and structure, and produce stable behavior or fail, as is the case with many diseases.

Such an ambitious enterprise requires a wide range of skills encompassing many disciplines. The knowledge needed to produce this new system-level understanding includes understanding of cell-cell interactions in response to mechanical, electrical, and biochemical signals, genetic regulation of cell differentiation, multiscale physics-based computer simulations, nanotechnologies for micropatterning of molecules and cells in tissue engineering, and stem cell biology. The University has substantial expertise in all these areas.

Intellectual and Technological Issues

The central issue facing researchers hoping to understand biological systems can be stated as a question: How does the information encoded in the genome interact with environmental and self-generated stimuli to produce functional and dynamically adaptive, three-dimensional structures, such as tissues and organs? And furthermore, how is the function of those cells, tissues, and organs controlled at the organismal level during development?

For instance, the stability of form that characterizes tissues and organs results from integration of local behavior with the system. Local output, in turn, is dependent on global, distributed properties. It is this multiple input, multilevel processing, and integrated output that life scientists have not been able to capture analytically, limiting them to measurements on individual cells or group of cells. Science has learned much about cells but mostly as

generic entities in artificial situations. We must learn about cells when they are involved in real situations such as making or remodeling, a particular tissue.

Life scientists need to answer the following major questions:

1. How do organisms achieve a three-dimensional structure in time?
 - How do cells acquire their identity?
 - How do cells recognize and adapt to their environment?
 - What is the nature of forces that produce patterns and shapes in cells, tissues, and organisms?
 - How do force and energy balance constrain processes?
 - Can pattern and form be predicted and modeled?
 - How does energy determine intra- and inter-cellular interactions?
 - What are the minimal requirements, regulatory molecules, and mechanisms that control and maintain life, identity and diversity?
2. How do biological stimuli and environment translate into a coordinated, integrated behavior?
 - How does local behavior result in aggregate behavior?
 - How do molecular systems process information?
 - How is global integrity (homeostasis) maintained in the face of local failure?
 - How are chemical processes, mechanics, and gene expression integrated to produce complex biological organs and systems with a particular function, location, size, and shape?
 - How do internal and external signals interact to establish and maintain identity?

Addressing these questions will promote fruitful interdisciplinary collaboration. For instance, to probe specific structures within a living tissue or organism we will need to link with efforts in nanotechnology and robotics to help us guide smart molecules and bio-machines throughout the intricate landscape of a tissue. Indeed, we foresee synergistic interactions between this initiative and both the information technology and nanotechnology initiatives.

The initiative will also require us to strengthen existing programs. Researchers in stem cell biology will be instrumental to understanding the signals that control cell identity. Researchers in chemistry and pharmacology will help design small molecules and drugs to define the function and fate of important molecules. Spectroscopists will develop new methods to visualize structural and functional changes. Material scientists will make synthetic or hybrid matrices to allow us to test hypotheses about motility and adhesion in response to environments with different physical and chemical properties.

The focus area is transformative. It will advance both research and education for a wide variety of disciplines. Building on our existing strengths, the University has the potential to be at the forefront of the most exciting challenge in life sciences of this new century.

The Initiative and Its Rationale

We propose that the University create an Institute for Biodifferentiation, comprising a broad selection of existing faculty from the School of Medicine, the School of Engineering and Applied Science, and the College of Arts & Sciences, fifty new faculty, and a new facility to house the activity of the institute. We would select an eminent scholar to lead the institute.

In the pursuit of its vision, the institute will have two complementary components: fundamental discovery and applied discovery:

Fundamental discovery will address the basic mechanisms whereby cells differentiate and arrange spatially and temporally in a structure that is capable of performing the specialized function of tissues, organs, and organisms. We will pursue four overlapping and intimately related fields of knowledge: differentiation, morphogenesis, organogenesis, and systems integration. Studies will include but not be limited to:

- Identifying the gene/protein pathways that determine and maintain cell/tissue identity in mammals as well as in more genetically tractable organisms.
- Elucidating the physical determinants of tissue/organ shape and their molecular and genetic basis.
- Defining the intracellular and environmental signals that guide and maintain tissue development and integrity, and integrated biological function.
- Studying the differentiation that occurs during tumorigenesis and wound healing.
- Understanding how cell, tissue, and organ systems function at the organism level during development.

Applied discovery will utilize basic knowledge to generate products and techniques that will enhance our capacity to perform fundamental research, benefit human health, and stimulate our economy. Our goals include:

- Producing long-lasting, fully compatible and functional tissues and organs—liver, skin, bone, kidney, pancreatic islets, and blood vessels.
- Regenerating congenitally defective organs or tissues damaged by acquired disease.
- Repairing organ structure or restoring function using cell transplantation and/or gene therapy.
- Designing more effective pharmaceuticals and drugs.

In addition, these projects may lead to new diagnostic reagents for medical and research purposes, vaccines, tumoral markers, susceptibility tests (toxicants, infectious agents, environmental pollutants, bioterrorism), individualized and population-based nutritional/life-style/pharmacological interventions, and advances in DNA computing.

One and possibly two new buildings will be essential for co-locating sufficient laboratories with complementary strengths to make the institute truly most effective. Common meeting and instructional facilities are also essential. Such a structure or set of structures will give us an advantage over our competitors. From a practical point of view, there is no other mechanism than a new building to bring together the diverse groups of scientists required for this venture because there is no way to house them in existing laboratories.

To hire fifty new faculty to build strength in the several fields needed for this initiative is clearly a costly and complex venture. A key feature of our proposed research focus is that the expertise required for it is also critical for broad-based advances in biological knowledge. This will strengthen the life sciences at the University as a whole. For instance, the addition of five positions in morphogenesis, three positions in stem cell biology, and three positions in tissue/systems engineering would turn a prominent group of developmental biologists into a world-class group. Similar targeted hiring in cell biology, biomedical engineering, and pediatrics would have similar impact. At the same time, this initiative will deliver completely new strengths to the University.

Although the institute itself will not offer degrees, it will support a lively educational mission. Students will participate in all the activities of the institute, and it is anticipated that the institute will have an impact on teaching and training at all levels within the University. Undergraduates will be exposed to new courses in such areas as physiology, organogenesis, genomics, tissue engineering, and bioethics. At the graduate level, students will join the institute through existing graduate programs. Training grant opportunities within the institute will provide new sources of funding for students and will attract excellent students from around the country. At the postdoctoral level, the commission proposes that a set of distinguished fellowships be created to attract the best young investigators. A yearly international symposium at the institute will focus attention on its activities and encourage interaction with key researchers around the world.

We estimate the cost for establishing fifty faculty lines, erecting an institute building, and funding fellowships and curriculum development at \$150 million. As mentioned above, an institute could be created in phases, thus spreading out the cost. In addition, the proposed

hiring strategy and building should allow existing departments to redirect space and faculty lines to develop other initiatives that are now constrained by lack of resources.

Prospects for Success

The commission believes that such an initiative would enjoy widespread success, for a number of reasons. The University has a strong base for pursuing the proposed initiative. We already have leadership in four key areas—morphogenesis, bioengineering, systems physiology/pathology, and organogenesis—as well as substantial strengths in applied genomics, cancer biology, signal transduction, information technology, and cardiovascular biology.

For instance, our expertise in proteomics and genomics will be fundamental to identifying genes and proteins involved in growth and development, and the application of bioinformatics will allow us to assign potential functions to a gene or group of genes and guide experiments. Our departments of Molecular Physiology and Biomedical Engineering are ranked third and fifteenth in the nation by *U.S. New & World Report*. Strategic use of expertise in biomedical engineering, physics, mathematics, and computer science will allow us to study and model groups of genes and entire molecular pathways that control growth, morphogenesis (embryonic and evolutionary development of the structure of an organism), and remodeling of tissues in response to injury.

Based on our existing strengths, faculty recruitment in several key areas should elevate us to a position of international leadership. For instance, the Keck Center for Cellular Imaging is a leader in the technology that permits study of dynamic real-time interactions of molecules and processes in three-dimensional, live tissue over time. The Free Electron Laser initiative, if successful, will provide us with the opportunity to visualize molecular interactions among cells with an unprecedented degree of resolution.

Enthusiasm for the research to be undertaken under the direction of the institute is already high at National Institutes of Health, so that over the long term federal funding will be available. Indeed, several of the components of the proposed institute are already funded at the University. Discussion of this initiative has already resulted in submission of new research proposal. Mobilizing and organizing our efforts under the auspices of a strong institute will attract additional support from the government as well as support from private donors and industry.

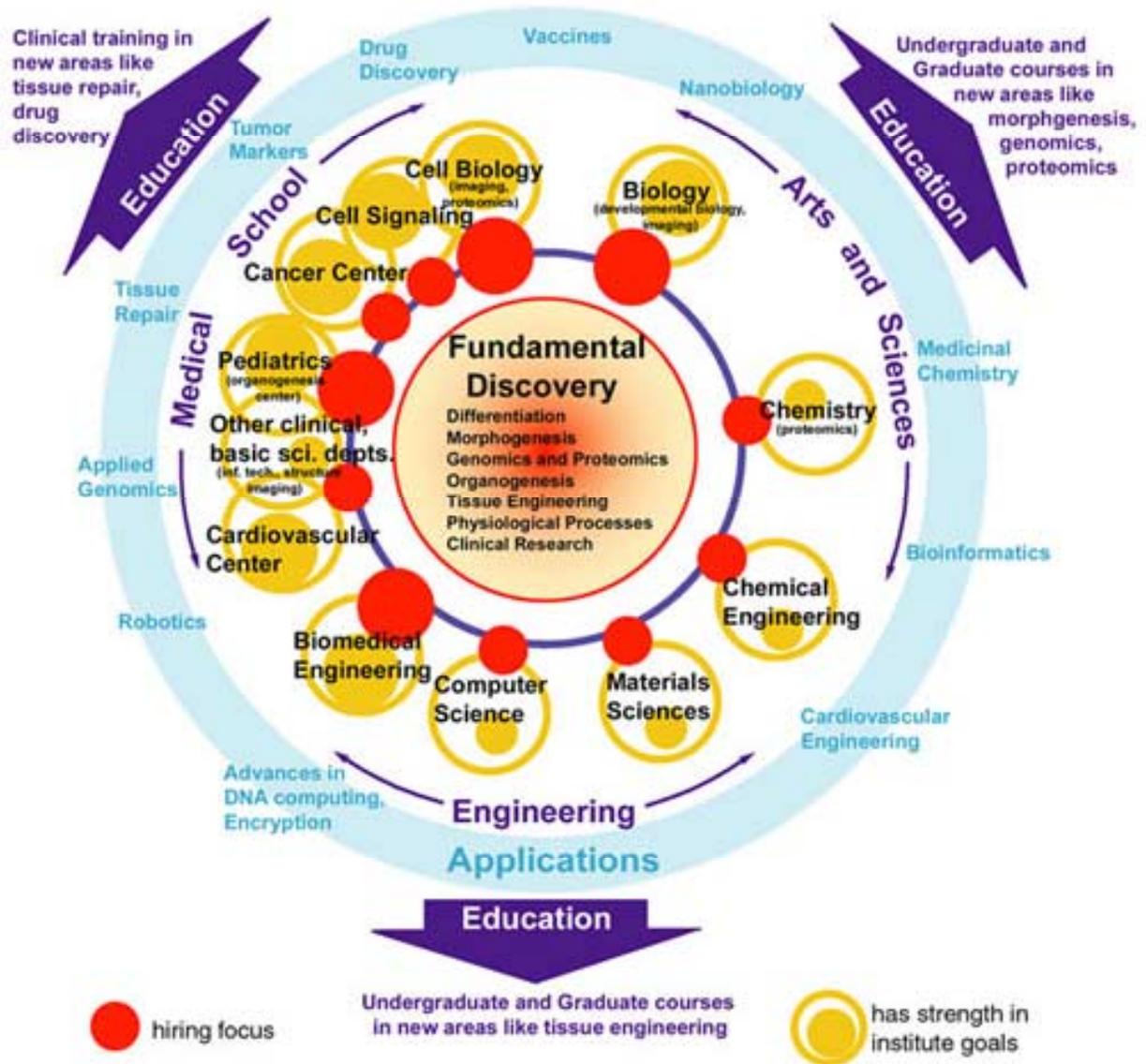
Recommendation 3:

Create an interdisciplinary Biodifferentiation Institute (see Figure 1 below). The mission of the institute will be to answer the question of how cells and organisms acquire and maintain their characteristic form and function, to understand how this process goes awry in disease states, and to apply acquired knowledge to preserving human health.

- The institute director should be a recognized leader in a major scientific area of the institute. The director will report to the vice president for research and public service. An advisory board composed of representatives from the three schools and extramural experts will assist the director with major programmatic decisions of the institute.
- A new building (100,000 square feet) will be necessary to house existing and fifty new faculty jointly appointed in the institute and one or more existing departments. Faculty recruitment should be phased. Initial recruitment of ten faculty in key areas such as stem cell biology, morphogenesis, and tissue engineering will virtually assure national prominence.
- The University should designate approximately \$150 million to support construction of the building, recruitment of faculty, and development of the overall program.

Figure 1

Biodifferentiation Institute



Recommendations for Sustaining Long-Term Excellence

Recommendation 4:

Strategically Advance Excellence in Science and Engineering

Challenges and Opportunities

The unprecedented growth of knowledge in the last thirty years has made it more difficult for academic departments to acquire expertise in all aspects of their discipline. There has been a great proliferation of subfields in each discipline and an expanding body of knowledge associated with each one. While some academic departments in the past may have aspired to excellence in the subject matter of every subfield, the sheer cost of such an endeavor typically makes it impossible today. Currently, departments achieve selective excellence by strategically building depth in a set of carefully selected subfields.

Despite severe fiscal constraints, the University has managed to build clusters of strengths within many departments in science and engineering. Some of these clusters are illustrated in **Appendix B** as well as being cited as the basis for the development of the three focus area initiatives.

Successful departments do more than build excellence. They retain the capacity to evolve and change as knowledge in their discipline changes. Departments can do this only by maintaining sufficient faculty in major subfields to be able to identify new opportunities for research and discovery as they arise. It requires strategic thought and action. Departments create strategic plans, target subfields for development, and hire faculty—both eminent scholars and newly minted Ph.D.s—with the specific talent set that they require.

Underlying Issues

To a certain extent, size is an issue in determining a department's success. When compared to the top twenty departments in their field, the size of the UVa faculty in the natural sciences is 34 percent smaller, according to the most recent NRC report. This is in contrast to the humanities at the University, where faculty sizes already equal or exceed the average of those ranked in the top twenty. When departments are too small, they lack the critical mass needed to develop expertise around a cluster of subfields and they lack the broad knowledge of their field necessary to capitalize on new opportunities. Thus, it is not absolute size but sufficient size that is important.

Maintaining a strategically appropriate size is, of course, a matter of funding. In science and engineering, funding goes beyond finding resources for faculty salaries. In most cases, hir-

ing faculty members requires substantial initial start-up investment in the creation or renovation of laboratory space, in equipment, and in technical support. Depending on the experimental nature of the field and level of appointment, start-up costs range from \$50,000 to \$1 million or more.

The commission finds that the science and engineering departments at the University lack the size and resources to act strategically. Currently, there are fifteen vacancies in the science departments in the college that have not been replaced because lack of start-up funds precludes hiring an individual of the quality that we require. Reductions of state support earlier in the decade have been particularly debilitating. Ten more retirements in the college are anticipated within the next five years. The lack of start-up funds also afflicts the engineering and medical schools in similar ways. The impact of these vacancies on teaching and research is negative: Class sizes in core undergraduate courses are larger, offerings at the upper level undergraduate and the graduate level are reduced, and the increased time constraints on existing faculty impede the development of innovative teaching and research projects.

The Initiative and Its Rationale

The commission recommends that the University establish an endowment for the strategic investment in new faculty. The provost(s) should allocate the proceeds from the endowment with the goal of enhancing faculty excellence. Allocations should be strategic and opportunistic. The goal for this endowment should be to build the science and engineering departments according to the strategic plan of the schools and with the eventual goal of increasing quality in all departments. This endowment, which would complement the multidisciplinary focus initiatives, should eventually lead to balance across the science and engineering departments.

Prospects for Success

The success of this recommendation, as well as that of the commission's first three recommendations, rests on clusters of strengths that exist throughout the sciences and engineering. The very existence of these clusters of excellence is a sign of the determination of our faculty to generate new ideas and to act on them. Additional faculty, allocated in support of the strategic vision already in place at the school and department level, will enable our current faculty to take nationally respected programs and make them international leaders.

The capital campaign has shown that substantial funding for faculty start-ups and facilities can be found for faculty support if donors have the opportunity to understand the importance of appointments in strategic areas. For example, significant funds from donors were the key factor in enabling ground breaking for a new environmental sciences building in the summer of 2000, a project that will nearly double research space and endow faculty positions. The astronomy department recently received a \$10 million gift, which it will use to

enhance its innovative program in optical and infrared instrumentation. This donation will help it participate in a world-class telescope project.

Recommendation 4:

Support *strategic* new faculty appointments by providing stable, long-lived resources to fund the start-up costs of equipping and renovating associated laboratories.

- Establish a \$100 million endowment for this purpose to be administered competitively through the provost(s).
- Support growth in disciplines when opportunities to build excellence in areas identified by school and departmental strategic plans are identified.
- Target opportunities across all areas of science and engineering, paying particular attention to those outside any current University initiatives, but act opportunistically and strategically.
- Request new faculty salary lines from the state, as growth requires.

Recommendation 5:

Improve the Quality of Ph.D. Graduate Education

Challenges and Opportunities

Graduate education and graduate students are fundamental to the science and engineering enterprise of any research university. The ability of faculty to achieve their research goals typically is critically dependent on the talent and the efforts of graduate students. Much of the intellectual vitality of research revolves around the graduate seminar courses in which faculty and students alike probe all that is known on a particular topic. Graduate students are researchers who work side by side with their faculty mentors almost as soon as they arrive at the University. They gain expertise and experience in faculty laboratories and by tackling significant intellectual problems under the direction of senior scholars.

Graduate students also play a vital role in undergraduate education, where they serve as teachers, tutors, and mentors. Graduate student teaching and participation in course laboratories greatly influence the quality and vibrancy of the undergraduate education experience. Under the direction of senior faculty, graduate students often work closely with undergraduate students in large lower-division courses. It is also common at the University to involve undergraduates in research—very early in their careers. A relationship arises between undergraduates and graduate students, who serve as role models, teammates, and sometimes project managers for the undergraduates.

Because of their pivotal role in research and in undergraduate education, graduate student quality directly affects the quality of the faculty who can be recruited. Not surprisingly, the opportunity to work with outstanding graduate students is a powerful inducement for prospective faculty. Universities with excellent graduate students find it easier to recruit and retain the most distinguished scholars.

Attracting the best young people to graduate school is increasingly difficult. Impressive salaries and other benefits offered by the private sector lead many of the most talented students, particularly in engineering, to go directly to industry or to postpone graduate education. Consequently, competition among research universities for talented students who opt to continue their education is intense.

Many of our peer institutions deploy considerably more resources to attract and retain these students than does the University of Virginia. For instance, Stanford has launched a drive to secure a \$200-million endowment that will support in perpetuity 300 graduate students a year in science and technology. Each student will be supported for three years. Students receiving these fellowships are free to choose their research projects and are not dependent on external funding of a research project.

On the average, our graduate students are not comparable to our truly superior undergraduates. The latest *U.S. News & World Report* ranks the graduate program of the

School of Engineering as thirty-sixth nationally. However, our graduate students are ranked forty-second on their quantitative Graduate Record Exam (GRE) scores and thirty-ninth based on their analytical GRE scores. In other words, the quality of our graduate students, using these measures, depresses the standing of the school. In addition, in some fields we note that students come to the University to earn a masters' degree, then move to a more highly ranked school for their Ph.D. This can be very disruptive to research.

The commission believes that our quest to raise the stature of science and engineering at the University can only be achieved if we develop a vigorous, coherent program to recruit and retain the very best graduate students, and if we provide them with an exceptional educational experience.

Underlying Issues

Our graduate programs have several weaknesses. One is size. Our departments, in many cases, are too small to offer as wide a range of research options and graduate courses as our competitors. Filling existing faculty vacancies, strategic hiring, and the development of the focus areas will all help to address this problem, but much more needs to be done to attract the high-quality graduate students essential to our programs.

The stipends and benefit packages that we offer are just barely competitive with the other universities. At UVa, graduate funding became a critical problem during the decade of the 1990s. Reduction in state support and increases in tuition during the first half of the decade rapidly increased per-student tuition costs. These financial pressures have continued as state funding for the tuition reductions of the past several years have been limited entirely to in-state undergraduate students.

A particular problem is the inadequacy of funds, known as tuition differentials, to pay the difference between in-state and out-of-state tuition. Most competing institutions provide complete tuition remission for graduate students supported by fellowships, teaching assistantships, or research assistantships. At the current time, the University provides only limited tuition remission. In particular, the funds for the tuition differentials in college are inadequate and are likely to become inadequate in engineering. To be competitive, departments provide tuition differential from other funds.

Limits on funds often lead to limits on course enrollments that then constrain the breadth of graduate courses offered. Reducing graduate tuition at least to the level of in-state tuition for all students holding assistantships or fellowships is a fundamental need. In addition, most graduate programs now offer health insurance coverage to students supported by assistantships or fellowships. To be competitive, the University must also provide this benefit.

It is important that there be effective publicity about the graduate programs and the achievements of graduate students. The University has been successful in emphasizing undergraduate programs, particularly in planning documents and budget requests to the state, and could use a similar approach to promote graduate programs. Public understanding of the importance of graduate programs to the University's overall success needs to be im-

proved. It is especially important that we communicate the critical role that graduate training plays in providing the staff of technology-based activities.

The Initiative and Its Rationale

The quality of the programs we offer and the quality of the students we attract is inextricably related. If the University is to achieve preeminence in science and engineering, we must take steps both to improve programs and to attract better students.

Broadly, we need to deepen and expand the educational experiences that we offer to our graduate students. The commission recommends that the University support strategic school and departmental initiatives to increase the depth of graduate offerings in specific fields and to offer additional multidisciplinary seminars that would bring graduate students from multiple departments together in their intellectual pursuits. In some cases departments should also provide opportunities for graduate students to learn more about the transition of technology to industrial application. This includes learning about intellectual property rights and their management. Individual departments can pursue such initiatives, or they can be multidisciplinary efforts.

Some departments are offering courses and even majors via distance learning or in areas, such as Northern Virginia, outside of Charlottesville. We applaud such programs. Different departments elect to follow different avenues. The majority do not offer off-Grounds degrees, choosing to develop strength in on-Grounds, before addressing new student constituencies. Distance learning is a promising avenue that should be considered for graduate programs where the faculty believe that they wish to export such programs.

Finally, UVa would be well served by launching an aggressive campaign to internal as well as external audiences, publicizing the quality of our graduate programs and underlining the importance of graduate education to the intellectual life of the University.

Prospects for Success

The University has a number of innovative initiatives that can be viewed as prototypes for improving graduate education. The interdisciplinary neuroscience graduate program involves forty-nine faculty from the College and the Medical School. It offers sustained support to students and innovative multidisciplinary courses. Competition for a place in the program is intense. The astronomy department has embarked on a unique graduate training program in radio astronomy instrumentation that will be integrated with their growing optical and infrared instrumentation program. They have submitted a NSF proposal with a multi-disciplinary team from the astronomy department, the Curry School, physics, electrical engineering, and the local National Radio Astronomy Observatory.

The manufacturing systems center established by the School of Engineering at the Dominion Semiconductor facility in Manassas represents another fruitful initiative. This is the first laboratory of its kind located within a semiconductor plant. It provides graduate students with invaluable, first-hand exposure to quality and process control issues.

Another program—for the Science and Engineering of Laser Interaction with Matter—provides exposure to current applications of lasers in industry through workshops and summer internships at national laboratories and in industry.

The University has achieved encouraging success in attracting funds to endow graduate fellowships. For instance, the college has raised \$15 million for fellowships during the capital campaign. This shows that there is potential for building such endowment programs.

Recommendation 5:

Devote resources to improve the quality of graduate education at the University and attract the nation's very best graduate students.

- Establish a \$100-million fund to provide graduate fellowships, out-of-state tuition remission for funded graduate students, and health insurance benefits. These funds would be administered by the provost(s) and made available on a competitive basis.
- Support department and university-wide initiatives to improve graduate education and attract excellent graduate students.
- Promote the professional development of students. This may involve career planning, assistance in communication to non-native speakers of English, and the study of ethics, entrepreneurship, and intellectual property management.
- Launch an aggressive, national campaign to publicize the quality of our programs and to recruit exceptional graduate students.
- Expand distance learning courses or graduate programs at distant locations as faculty feel that the on-Grounds programs are strong and stable, providing the base for projection.

Recommendation 6:

Establish a Fund for Excellence in Science and Technology

Challenges and Opportunities

It is not enough simply to make choices for today, although this must be done. It is equally important to foster the innovative, speculative thinking that may form the foundations of future focus areas. One way to accomplish this is to encourage the exploration of novel research ideas. Most external funding agencies provide awards only to programs with track records that are proven to some degree. To help faculty members attain the standing needed to compete successfully for external funding, the University should be entrepreneurial. It can do this by providing very early seed funding for ideas that may be too original to gain approval from traditional organizations and for groups that are building new focus areas. Seeding truly innovative research is necessary if the University is to sustain its eminence into the future.

The Initiative and Its Rationale

The commission recommends the creation of a Fund for Excellence in Science and Technology. Its goal should be to increase the University's leadership in science and engineering research. This seed fund should nurture new ideas and new endeavors. It should not be limited to the focus areas in earlier recommendations. The president has already announced the establishment of this fund, providing for \$1 million in awards for the first year. These moneys, however, were to some extent reallocated from other sources. We recommend the infusion of new money, with the intention of increasing the annual size of the fund to \$5 million over five years.

Two categories of awards should be made from the fund.

- Exploratory Awards of up to \$10,000 should be used to support highly innovative (pilot) workshops, conferences, and symposia to assess the feasibility of new ideas as well as their potential to develop into full-scale research efforts. Groups or individuals applying for these awards must be able to enunciate a clear vision of their research. In some cases, Exploratory Awards will help teams preparing to compete for large, externally funded grants.
- Excellence Awards of between \$50,000 and \$500,000 over several years' duration should support individual or multidisciplinary groups of investigators proposing to solve a major scientific or technological problem. We envision that Excellence Awards will have an impact at the local and national level and will lead to important

advances. Groups that applied for an Exploratory Award are eligible to apply for an Excellence Award at a later date.

The Fund for Excellence in Science and Technology should be managed by the Office of the Vice President for Research and Public Service, who will be empowered to make the award selections. The vice president will assemble an independent advisory committee consisting of outstanding faculty regardless of rank and, perhaps, external experts from the physical sciences, the biological sciences, engineering, medicine, and other relevant fields to help guide award selections. A key criterion for the selection of Excellence Award projects should be their potential for garnering externally sponsored research funds from five to twenty or more times the fund's investment. Proposal topics can be drawn from any technical area. Faculty and students from all schools can participate in partnership with faculty and students from the sciences, engineering, and medicine.

The Vice President for Research and Public Service, in consultation with the advisory committee, is responsible for developing an effective, efficient awards process. The vice president will maintain formal written criteria for selection of the two categories of awards. Criteria might include:

- Merit of the proposed research.
- Potential for the proposed work to be the basis for an area of excellence within the University.
- Potential for subsequent extramural funding.
- Potential for the creation of intellectual property disclosure, where appropriate.

The vice president for research and public service, in consultation with the advisory committee, should determine reasonable requirements for form and content of proposals.

Prospects for Success

This proposal is modeled after the Academic Enhancement Program (AEP) as it was originally defined and in the form in which it was particularly successful. Analysis shows that most principal investigators who received AEP awards for research later received funding from other sources for related research that was between five and thirty times greater than the original award. In a few cases, the externally sponsored funds exceeded a factor of thirty.

Accordingly, one measure of the effectiveness of the seed fund is success in attracting additional funding for initiatives as well as the size of the resulting research program. Although these criteria are not a direct measure of quality, they do reflect the number of students, post docs, and faculty who choose to involve themselves in the project.

Recommendation 6:

Establish a long-lived Fund for Excellence in Science and Technology with a merit-based selection process to stimulate innovative research.

- Create a merit-based selection process managed from the Office of the Vice President for Research and Public Service and advised by a committee of outstanding faculty of all ranks.
- Select proposals that will help jump-start innovative research in science and engineering. One key metric should be the potential for that research to attract externally sponsored research funding as the research matures.
- Provide \$1 million in funds during the first year, growing the fund to a steady state of \$5 million of awards annually.

Recommendation 7:

Foster Strategic Central Leadership

Challenges and Opportunities

The commission believes that the University is not currently well organized to achieve excellence in science and technology, especially at a time when some of the most promising areas, such as those named in our first three recommendations, are inherently multidisciplinary. The many departments in science and engineering are spread across three schools administrated by three different deans reporting to two different provosts. Most resources are controlled at a relatively low level, in schools, departments, and centers. Each unit head, quite understandably, protects and advances his or her unit and allocates its resources accordingly. Administrators with responsibility that span the units—the academic provosts and the vice president for research and public service—control only modest resources. Maintaining excellence in science and engineering requires the ability to pool resources and to deploy them to achieve strategic, cross-unit goals. Under the current arrangement, opportunities are missed, and potential synergy is sometimes lost.

The three focus area recommendations together represent a step toward addressing these problems. Because each focus area involves faculty from at least three schools, each recommendation suggests the creation of an institute with substantial resources that is to a degree independent of any existing school. These institutes, however, are designed to focus on specific areas and should exist for as long as they have a substantive mission. Additional steps should be taken to improve overall strategic cooperation more broadly among schools and departments.

The consequences of the University's decentralized organizational structure are not confined to research but affect education as well. For example, there is no computer science major in the College of Arts & Sciences, nor do undergraduates in fields like mathematics or cognitive science have much opportunity to minor in it. Because of limited resources, the School of Engineering can barely meet the needs of its own students for computer science courses. Yet, we believe that there is great interest among college students in computer science degrees and computation literacy courses. School barriers have retarded the development of such programs.

The lack of a central strategic administrative post with both the resources and the specific responsibility for the science and engineering enterprise at the University has also undermined our ability to make our case for state support in these areas. We must be able to convey in a forceful manner both our achievements and our needs. We have a compelling vision for excellence. We need to present it to our increasingly receptive legislature. They have demanded comprehensive science and technology literacy for undergraduates. They recently created a fund to support strategic university research. They understand that basic

research activities attract new and expanded industry to the Commonwealth. Our central administration needs to present better cases to the legislature for increasing funding of science and engineering broadly, as well as for specific initiatives such as those recommended in this report. Faculty need to participate in this activity.

The Initiative and Its Rationale

The commission proposes that the University should consider reestablishing a single provost who is the academic leader of the entire University with overall responsibility for all education and research. Today we have two provosts. In the past, one Provost had academic duties combined with the responsibility for hospital management. Hospital management has recently been assigned to the Executive Vice President. In this era of multidisciplinary education and research, a single academic leader will serve the University better than splitting responsibilities across two offices.

The second central office that is crucial to science and engineering is that of the Vice President for Research and Public Service. That office reports directly to the President and indirectly to the Provost. This seems to work. It should not be altered.

Central administrators need to have more resources and the power to allocate them. The commission looked in depth at the allocation of the research and education budget, unit endowments, patent revenue, and indirect funds from sponsored programs. There are many sources of funds, and the deans elect to use funds from different sources in quite different ways in an attempt to achieve the greatest gain for their schools. It is not appropriate to reduce the funds available at the unit level and divert attention from pressing unit needs. Earlier recommendations specify some resources that should be administered in the central offices.

The Provost(s) and the Vice President should work closely with deans, faculty, and other administrators to develop an ongoing vision for science and technology at the University and to coordinate the allocation of funds and faculty line resources. We believe that the Provost(s) should more aggressively exercise authority over faculty lines to achieve strategic change. The Provost(s) should convene the strategy and decision meetings that the deans need and want. It should not be forgotten that all resources will, in the end, be allocated to activities in departments and schools. The challenge is to make the best and most highly-leveraged investments of those resources.

The Vice President for Research and Public Service should have direct responsibility for overseeing the focus area activities. Each new institute director should report to the Vice President, and also should have an advisory council. That council should include, among others, the deans whose faculty participate in the institute, so that there is a forum in which to mediate between and integrate across unit interests.

The Provost(s) and the Vice President for Research and Public Service must take responsibility for continually assessing barriers—organizational, financial, and intellectual—to improvement in science and technology and for developing strategies to overcome them. They must develop mechanisms such as the Fund for Excellence in Science and Technol-

ogy to identify areas of potential excellence and mobilize resources for them as well as to evaluate the continued viability of existing focus areas.

Finally, a primary objective of this commission is to chart a vision that can be the basis for fundraising. At the present time most fundraising is on a unit basis. Recommendations 1 through 6 of this report should emerge as development themes. We believe that these themes can be turned into powerful cases to attract private donations. To be effective in raising funds for the science and engineering enterprise we need to have compelling visions. Today, those visions are naturally multidisciplinary. A cooperative development campaign based on university-wide themes will in these cases serve the University better than piecemeal, restricted, unit-based fundraising. Specific focused department and school fundraising should also continue. One approach does not meet all donor interests and unit needs.

The commission discussed more sweeping schools changes. We discussed several alternative proposals, such as creating a new school of science and engineering by combining the mathematics and science departments in the college with all of the engineering departments. The pros and cons of separating the science departments from the humanities departments in the college are complex and need careful consideration. There was a suggestion to include the Ph.D.-granting science departments from the medical school as well. Although a number of members saw benefit in one restructuring or another, we were unable to build a consensus inside the commission for any particular proposal. However, the very fact that we are recommending three focus areas, each of which spans at least three schools, is evidence that our current school and department organization is not appropriate for research in science and engineering. Some members would argue that it is outmoded for education as well. We concluded that the commission should sponsor some forums in which to discuss alternative organizations.

Prospects for Success

Instances in which there has been cooperation across organizational lines have produced dramatic results. Inspired leadership led to the creation of the Department of Biomedical Engineering under the joint auspices of the School of Medicine and the School of Engineering. This was a key element in the department's impressive win of a multimillion-dollar Whitaker Foundation grant and its high ranking in *U.S. News & World Report*. Another significant success has been the National Science Foundation Center for Biological Timing. The School of Medicine and the College of Arts & Sciences pooled resources to create this center, which has consistently received high marks from outside reviewers and attracted nearly \$20 million in sponsored research funds since its inception.

Such initiatives, however, are often the result of happenstance, rather than deliberation. Under the present structure, multidisciplinary ideas are difficult to initiate and implement and consequently do not occur with the frequency needed to sustain long-term excellence in science and engineering at the University. This recommendation is designed to enable the University to make decisions affecting science, medicine, and engineering in a strategic and directed manner.

Recommendation 7:

Strengthen central leadership, charge it with formulating and communicating a broadly-based strategy for science and engineering for the University, and empower it with resources to implement strategically important programs.

- The University should consider reestablishing a single provost, who would serve as the academic leader of the entire University. This is feasible now that hospital management has been assigned to the Executive Vice President. All academic units would report to this provost, who would be able to more aggressively exercise authority over faculty lines to achieve strategic change.
- New resources should be allocated to and administered by the central administration so that they can take cross-unit strategic actions. Patent Foundation revenue is one such source of funds.
- Each new institute should have an advisory council that includes at least deans of those schools whose faculty are involved in the institute, so that there is a forum in which to mediate between and integrate across unit interests.
- The Vice President for Development should use our first six recommendations for thematic, cross-unit fund raising. Schools should materially participate in cooperative theme-based development when they have common interests and in ways that those interests are honored.
- The commission should sponsor faculty discussion of alternatives for University organization that might better support our future education and research activities.

Implementation of the Commission's Recommendations

There will be a series of public forums on the report, requesting suggestions, and explaining the underlying factors that motivate our proposals. The members of the commission are prepared to assist with the implementation of the commission's recommendations for the focus area initiatives.

In addition, we will be available to assist in the development of strategies for seeking external research support from the federal and state agencies, the Commonwealth Technology Research Fund, foundations, and industry. We anticipate that there will be multiple opportunities to create large government-funded projects within the context of the focus area initiatives. We believe implementation plans should consider partnerships that might be forged with other universities in the Commonwealth and the nation, with industry, and with the national laboratories. Such partnerships are crucial to both winning very large government funding and also to being a leader in the education and research community.

We will also be available to help as needed with the implementation plans for recommendations four through six. Implementation plans should also provide guidelines for seeking support from the state. We will be available to work with the University administration to devise plans for formally approaching the state government, including the legislature, for support. It is essential that faculty leaders help educate the legislature about our achievements in science and engineering and about the ways our activities advance the Commonwealth in terms of quality of education delivered, partnership with industry, outreach, and maintaining a research infrastructure that contributes to economic development. We believe that compelling cases must be developed to convince state leaders that societal and economic benefits will flow if new lines, new faculty funding, and additional start-up funds are made available in science and engineering.

A number of our recommendations contemplate—and may depend on—donor support. We have already discussed with deans and members of the central administration raising endowment for the purposes set out in the recommendations. We have suggested that in some cases development efforts should be organized around University-wide themes. We are prepared to help in planning University development efforts.

Metrics and Evaluation

This commission is requesting the investment of very substantial resources. This requires thoughtful and strategic management of resources to gain the most value. The results of implementation actions need to be periodically measured and evaluated. As part of the focus area initiative implementation plans, we should create assessment guidelines to periodically evaluate expected, articulated, incremental outcomes. We would include formal evaluations from outside evaluators. We should also compare ourselves to our own past performance and to the performance of our peers and competitors. Initiative metrics may include, for example, number of undergraduates, graduates, and post-docs involved; quality of those students and post-docs; citation statistics; patents issued; sponsored funding levels; rankings of related disciplines; and stature of the faculty involved.

Our expectations are high. The commission believes that if the initial early investment and resources are deployed in a timely manner, the University will have five science and engineering disciplines in the top-ten percentile of the NRC rankings and ten disciplines in the top-twenty percentile by 2020.

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Appendix A:

Peers and Competitors

It is critical to consider the University in the context of its peers and its competitors. The initiatives they take form a useful standard against which to measure the quality of our efforts, given our unique aspirations and heritage. They provide both a benchmark and a road map. The actions of our peers and competitors also have a direct impact on our future. Given the finite quantity of top-quality students, faculty, and available resources at any specific time, the actions taken by our peers will affect the University's own prospects.

As recently as three decades ago, the University of Virginia was a regional institution with limited aspirations. Strong, determined, central leadership and widespread, enthusiastic support from alumni and friends have broadened our horizons and transformed UVa into one of the leading public universities in the nation. For more than a decade now, *U.S. News & World Report* has rated us among the very best, if not the very best, of national public universities. From a general point of view, this group of powerful, state-supported institutions comprises our peers and competitors.

In science and technology, however, our competitors are more extensive and more varied. In these fields, the search for truth is both unrelenting and broad-based. It is certainly not limited to the nation's public universities. If we are to participate in the constant stream of advances that characterize science and engineering in our era, we must also match ourselves against *all* producers of knowledge, including the nation's best private institutions.

We have performed well in this regard up until now. The University has been a member of an elite group of twenty-five universities that *U.S. News & World Report* considers the pride of the nation. At times during the last ten years, the University has broken into the top twenty, a remarkable achievement given the cutback in state funding in the 1990s. The consequences of this rise to prominence are everywhere visible, from the new facilities for law and business to the superb quality of our students to the unprecedented distinction of our faculty.

A close look at the rankings, however, reveals that the University has not gained on its peer and competitor institutions during the decade. The 1989 *U.S. News* rankings placed the University twentieth among all universities and first among the nation's public institutions. In 2000, the University was ranked twentieth and first. Despite the remarkable achievements of many of our programs over the past ten years and the unprecedented success of the capital campaign, we are only holding our own.

The basis for our preeminence is the excellence of programs in the humanities, in law and in business. A majority of the public institutions in the top ten, as **Table 1** indicates, outperforms us in graduate engineering and medicine, often by a sizable margin. We are similarly outperformed in the sciences, as indicated by *U.S. News & World Report* evaluations of graduate programs in these fields. For instance, the University of California at Berkeley,

currently in a tie with the University of Virginia as the top national public university, is ranked third in biological sciences, first in chemistry, second in math, third in physics, and third in computer science. The University of California at Los Angeles, another close peer and competitor, is ranked twenty-third in biological sciences, eleventh in chemistry, and twelfth in math. The only graduate science program at the University of Virginia appearing in these rankings is psychology, which is ranked sixteenth.

TABLE 1: U.S. NEWS & WORLD REPORT RANKINGS—AUGUST 2000

School	Public Rank	Engineering Rank	Medicine Rank
University of California at Berkeley	1	3	N/A
University of Virginia	1	36	30
University of California at Los Angeles	3	21	10
University of Michigan at Ann Arbor	3	4	12
University of North Carolina at Chapel Hill	3	N/A	23
College of William and Mary	6	N/A	N/A
University of California at San Diego	7	15	23
Georgia Institute of Technology	8	4	N/A
University of Wisconsin at Madison	8	14	31
University of California at Davis	10	36	N/R
University of California at Irvine	10	N/R	N/R
University of Illinois at Urbana-Champaign	10	6	N/R

N/A = Not Applicable; N/R = Not Ranked

These findings are reinforced by the last National Research Council (NRC) rankings of graduate programs. Published in 1995, these rankings are generally considered to be the best overall competitive measures of performance among research universities. The council's rankings of faculty quality were based on such measures as percentage of faculty with research support, percentage of faculty publishing during the period under review, and faculty citations in scholarly publications. Since they reflect a comprehensive, peer review evaluation that emphasizes scholarship, NRC rankings closely correlate with a university's ability to attract research funding.

Like the *U.S. News* rankings, the NRC's revealed a pattern of weakness in science, medicine, and engineering. With the exception of physiology, the University had no graduate programs among the top ten in these areas, as **Table 2** indicates. By contrast, our peers among the public and private universities were quite strong. For example, the University of California at Berkeley has eighteen, while Stanford University of California had nineteen.

Further analysis of these rankings suggests that the University is not well-positioned to gain ground on its competitors in medicine, science, and engineering. It lacks both breadth and depth in its programs. The University offered only eighteen graduate programs among the biological and physical sciences and engineering disciplines reviewed by the NRC. Only

one, as we have seen, was in the top ten. The University of California at Berkeley had eighteen programs in the top ten.

**TABLE 2: UNIVERSITIES WITH GRADUATE PROGRAMS
IN THE TOP TEN*
NATIONAL RESEARCH COUNCIL, 1995**

Rank	Institution	Total Programs in Top 10	Arts & Humanities	Biological Sciences	Engineering	Physical Sciences	Social & Behavioral Sciences
1	University of California at Berkeley	35	10	4	7	7	7
2	Stanford University	31	6	5	7	7	6
3	Harvard University	26	9	5	0	6	6
4	Princeton University	22	9	1	5	4	3
5	Massachusetts Institute of Technology	20	2	3	7	7	1
6	Cornell University	19	7	1	5	6	0
7	Yale University	19	7	6	0	1	5
8	University of Chicago	18	6	1	0	6	5
9	University of Pennsylvania	15	7	3	2	0	3
10	University of California at San Diego	14	0	6	3	2	3
10	Columbia University	14	6	3	0	4	1
10	University of Michigan	14	4	0	5	1	4
10	University of Wisconsin	14	2	3	2	3	4
14	University of California at Los Angeles	13	3	1	2	1	6
14	California Institute of Technology	13	0	4	5	4	0
16	University of Illinois—Urbana	10	1	0	5	3	1
16	University of Washington	10	0	4	1	3	2
18	Johns Hopkins University	9	3	4	1	0	1
19	Duke University	8	5	2	1	0	0
20	University of Texas at Austin	7	1	1	3	2	0
21	Northwestern	6	1	0	3	0	2

21	University of San Francisco	6	0	5	1	0	0
23	University of Virginia	5	4	1	0	0	0
23	Purdue University	5	0	0	4	1	0
23	University of Minnesota	5	0	0	2	0	3

*Public universities are indicated by shaded rows.

Raising the quality of programs and advancing them to the top ten in their field will be difficult, but there is cause for optimism. As **Table 3** shows, only four UVa programs appeared in the top quartile: physiology, psychology, pharmacology, and cellular and developmental biology. Twelve of our science and technology departments were in the second quartile, and three were in the third quartile. Given the right circumstances, however, our faculty has demonstrated its ability to boost the quality of their department dramatically. Current *U.S. News & World Report* rankings place the University's Department of Biomedical Engineering fifteenth in the nation and our Department of Materials Science twenty-first, a substantial change over five years. In both instances, interdepartmental and, in the case of biomedical engineering, interschool cooperation paved the way for this improvement.

A key requirement for raising our place in the rankings is to seek strategic opportunities to increase faculty size. Statistical analysis from major universities across the United States shows that NRC rankings correlate with faculty size. For instance, departmental faculty size in the humanities is 2 percent higher than average when compared to the top twenty NRC departments (68 percent higher in English); in the sciences faculty size is 34 percent less.

**TABLE 3: RANKINGS OF UNIVERSITY OF VIRGINIA
GRADUATE PROGRAMS
NATIONAL RESEARCH COUNCIL, 1995***

Quartile	Discipline	Rank/Total	Percentile**
1	Physiology	9.5/140	7
	Psychology	19.5/185	11
	Pharmacology	24.5/127	19
	Cellular & Developmental Biology	41/178	23
2	Chemistry	43/168	26
	Neuroscience	31/102	30
	Biochemistry/Molecular Biology	59.5/194	31
	Physics	45.5/147	31
	Computer Science	35/108	32
	Mathematics	45/139	32
	Chemical Engineering	30.5/93	33

	Materials Science	23/45	35**
	Mechanical Engineering	40/109	37
	Ecology, Evolution, & Behavioral Science	49/128	38
	Electrical Engineering	54.5/126	43
	Civil Engineering	39/86	45
3	Astrophysics & Astronomy	17/33	52**
	Biomedical Engineering	21/38	55**
	Molecular & General Genetics	62/103	60

*These are faculty quality rankings that measure scholarly activity. Educational output rankings produce similar results.

**Percentile rankings may be skewed by the small number of departments evaluated by the NRC in a particular discipline.

The conclusion is starkly obvious: The University has the potential for excellence in science, engineering, and medicine, but it must make a concerted effort immediately to support these programs. If it fails to do so, it will not only slide from the top of the list of public institutions, it will also drop out of the top twenty-five national universities, which is dominated by private institutions with extremely large endowments and the will to use their endowments to attract stellar faculty and build new facilities.

Moving science and technology at this University to the first rank will be a difficult and costly enterprise for a number of reasons. Our peers and competitors are continuing to allocate large sums for advances in science, engineering, and medicine, focusing on fields in which they already have an advantage as well as fields in which they see strategic opportunities. A few examples of investments by public universities include:

- University of California at Berkeley is launching a \$500-million dollar research initiative bringing together physical and biological scientists and engineers, including \$300 million for new facilities.
- University of California at Los Angeles has broken ground for a \$1.3-billion hospital and research complex.
- The University of Michigan has targeted \$200 million to create an Institute for the Study of Biological Complexity and Human Values.
- Georgia Tech has launched an initiative to create an information technology complex starting with a new \$70-million advanced computing technology building. It recently completed a \$30-million bioengineering and bioscience building, the first in a four-building biocomplex.

These initiatives indicate that the nation's best public universities are making hard decisions about their future. The scale on which these decisions are being enacted is illustrated in the following examples:

- Harvard is devoting \$200 million for research in genomics and proteomics, imaging and mesoscale structures, neuroscience, computer research, and evolution and global climate change.
- Princeton has raised \$60 million for a new Institute for Genomic Analysis.
- The California Institute of Technology is raising funding for a \$100-million biological sciences initiative.
- Yale is spending \$500 million to expand and modernize its facilities in science and engineering.
- Stanford received \$150 million from Silicon Valley entrepreneur Jim Clark to launch Bio-X, a program designed to give Stanford a leading role in biotechnology and biomedicine.
- Stanford has launched a drive to secure a \$200 million endowment that will support in perpetuity 300 graduate students a year in science and technology, each student for a period of three years.
- MIT received a commitment of \$350 million from International Data chairman Patrick McGovern to fund an Institute for Brain Research.

These initiatives reflect a recognition on the part of all our peers and competitors in science and technology—which include the nation's most powerful private universities as well as our public peers—that they must make a substantial investment of resources if they are to play a decisive role in creating the knowledge that will define the new century. The University of Virginia faces the same decision. To continue to grow and flourish as an institution and to play a leadership role in determining the future of society, it must not only expend comparable sums on strengthening science and technology, but it must allocate these sums strategically to create centers of excellence.

Appendix B: Areas of Strength

UVa possesses extraordinary variety, vitality, and strength in teaching and research across the disciplines of science and engineering. Given space, staffing, and resource constraints, our faculty have shown an extraordinary capacity for identifying opportunities, developing programs, and producing noteworthy results.

In this appendix, we highlight a selection of representative activities from the College of Arts & Sciences, the School of Medicine, and the School of Engineering and Applied Sciences chosen by the schools themselves. Together, they illustrate a proven record of excellence, spread broadly across the science and engineering programs at the University.

The College of Arts & Sciences

The areas of intellectual inquiry in Arts & Sciences that are within the scope of the Science and Technology Commission are located mainly in the Departments of Astronomy, Biology, Chemistry, Environmental Sciences, Mathematics, Physics, Psychology, and Statistics. Within the past two years, each of these departments has participated in the formal analysis, planning, evaluation, and response process conducted by the Provost's Office.

These reviews led to the development of academic plans that were discussed with the review committee and university administrators and revised in light of these discussions. Each department identified a number of areas of emphasis and identified key strengths and also resources that would be needed to develop their plans. While subsequent events have had some effect, these plans provide the best summary of current departmental strengths and goals.

Department of Astronomy

Astronomy has outstanding strength in **theoretical astrophysics**, fostered by the Virginia Institute for Theoretical Astronomy, and including the only active University faculty member in the National Academy of Sciences. Most of the faculty are also involved in both ground and space telescope observation. The Department maintains a close relationship with the National Radio Astronomy in Charlottesville. The key feature of the department's academic plan is to strengthen **experimental astrophysics**. This entails both development of an **instrumentation program in optical/infrared astronomy** and participation in a bold major telescope project. The department has recently received a large private gift that will enable real progress towards both of these goals.

- High energy astrophysics and extragalactic astronomy

- Supernovae, clusters of galaxies
- Formation of stars and planetary systems
- Positional astronomy: motions of stars and structure of the Milky Way
- Strong program in undergraduate education and public outreach.

Department of Biology

Biology has identified four areas of primary emphasis. **Morphogenesis** deals with the mechanism by which genetic information is translated into the three-dimensional structures that characterize specific types of cells in the early stages of development. This is a major area of strength within the department and will be a key part of the University-wide biodifferentiation initiative. A related emphasis is **neurogenetics and behavior**, which focuses on how development in the neurological system relates to such aspects of behavior as learning, memory, and biological timing. The third area of strength and emphasis is **evolutionary biology** in such fields as population genetics and evolutionary processes. A principal thrust for expansion in the department will be in the area of **genomics** and **proteomics**, which will apply the extraordinary recent advances in these two fields to specific problems in the other emphasis areas.

- NSF Center for Biological Timing
- Howard Hughes Foundation grant for curricular revision and laboratory modernization
- NIH training program in developmental biology
- Keck Center for Cellular Imaging
- Mountain Lake Biological Station.

Department of Chemistry

Chemistry has emphasized **biological chemistry**, **molecular spectroscopy** and **synthetic chemistry**. The department envisions continued concentration in these areas which provide the opportunity for interdisciplinary activities in **biomolecular structure and function**, design and discovery of new **polymers and catalysts**, and the use of **spectroscopic methods and techniques** for the study of materials ranging from nanoscale clusters of a few atoms to complex biological systems.

- Department consistently ranks in top ten nationally in American Chemical Society statistics for undergraduate degrees and per capita research grant funding

- NSF IGERT program (with Physics, School of Engineering, Norfolk State University, and Jefferson National Accelerator Facility) in laser interactions with matter
- Institute for Proteomics Research which promotes collaborative research with other University laboratories, other institutions, and industrial organizations on the structure and function of proteins.

Department of Environmental Sciences

Environmental Sciences is an interdisciplinary department of ecologists, hydrologists, geoscientists, and atmospheric scientists studying how the environment works and how people change and interact with the environment. The department has particular strengths in **ecosystem dynamics, global climate change, watershed science, and contaminant hydrology**. Future areas of expansion include **coastal dynamics** and **atmosphere-biosphere interaction**. Fundamental to these programs are the department's strengths in isotope geochemistry, environmental chemistry, climatological analysis, and ecosystem modeling. The department also addresses the broad concept of **environmental sustainability** by providing information and education programs, both through its curriculum and a university-wide program in **environmental literacy** that will promote understanding of how the environment works to the broader community.

- First comprehensive Environmental Sciences departments in the USA
- Ranked as one of top five departments and aims to be the best program in the country by 2020
- Field station network encompassing key ecological systems
- Two major laboratory construction projects totaling \$25 million underway.

Department of Mathematics

Mathematics has nationally recognized areas of strength in the algebraic areas of **representation theory, nonassociative algebras, and coding theory** as well as in the analytical areas of **mathematical physics, operator theory, and algebraic topology**. The department envisions maintaining its strengths in these areas as it builds interdisciplinary bridges between them and the other sciences.

In particular, mathematical physics, that is, the mathematics of modern quantum mechanics, has increasingly expanded its tools from the realm of analysis to that of algebra. In the 1980s, physicists developed the theory of quantum groups; their ideas were picked up by algebraists and used to obtain decisive results in modular representation theory (among them, results due to the Virginia department); these, in turn, were applied by physicists. Similarly, algebraic coding theory deals with the design of reliable methods of communicating digital information in the presence of noise and so provides the mathematics underlying

not only radio and telephone technology but also the error-correcting codes crucial to transmitting data accurately by computer and by satellite.

- GAANN (Graduate Assistance in Areas of National Need) grant from the U.S. Department of Education to support graduate program
- Program of emphasis years in targeted areas that bring in semester- and year-long visitors as well colloquium speakers
- Active research program for undergraduate students.

Department of Physics

The areas of strength in Physics include **atomic, condensed matter, elementary particle and nuclear physics**. The first two of these fields are applied to **materials** in the common sense of the word, and focus on understanding novel electronic, structural or optical properties. These studies are directly relevant to several of the target areas identified in the nanotechnology initiative. Elementary particle and nuclear physics probe the **fundamental nature of matter** at the sub-atomic level and deal with concepts such as nuclear forces, matter and antimatter. Experimental studies in these fields are typically conducted world-wide at major accelerator sites such as Fermilab in the US and CERN in Europe. The nuclear group is closely connected with the Jefferson National Accelerator Facility in Newport News. Physics also includes a strong theoretical effort that has as its goal construction of a **unified theoretical framework** that describes a wide range of experimental observations.

- Center for Atomic, Molecular and Optical Sciences has developed ultrafast laser facility
- Institute of Nuclear and Particle Physics has a major research effort at Jefferson National Laboratory in Newport News
- Research on use of polarized gases in medical diagnostics.

Department of Psychology

The fundamental goal of psychology is to understand human behavior. At one end of the spectrum this entails study of the **nervous system** at a structural level, including functional imaging. The department makes a major contribution to the inter-school Neuroscience Graduate Program. Others in the department study the development of humans and ask how perception, cognition, social and family interaction, and psychopathology are shaped by both biological traits and external influences. The department has strong programs in nearly every aspect of the process of **development**, ranging from neural development in animals to behavioral studies of children, adolescents, and the elderly. The study of **cognitive processes** includes efforts to understand how knowledge is acquired, organized and used. In the area of **social psychology** research deals with relationships, perception, identity,

introspection, communication, stress, and coping both under laboratory conditions and in natural settings.

- Department consistently ranked among top twenty nationally
- Major contributor to university-wide Neuroscience Program
- NIH training program in sensory system development and regeneration
- Leading role in undergraduate interdisciplinary program in Cognitive Science.

Department of Statistics

The Statistics Department specializes in application of probability and statistics in medicine, geoscience and reliability theory. Examples of research efforts are modeling of **dynamic feedback in hormonal systems**, **dynamic changes in the earth's tectonic plates**, **image processing methodologies** and models for the **reliability of materials and systems**.

- Strong interactions with biostatistics and other medical disciplines
- Statistical consultation with other faculty
- Undergraduate research participation.

In the Fall of 1999, the Dean asked the Arts & Sciences members of the VA-2020 commission to independently assess the science programs in the context of the commission's broader work. The group issued a report which made two key points: 1) improvements in the sciences must be built on a solid foundation including strong faculty, excellent facilities, and able graduate students; 2) new initiatives will ultimately depend on key people with the imagination, dedication, and support to create, define, and launch into new and rapidly developing scientific frontiers. With input from individual faculty and the department chairs, the Arts and Science group identified about twenty specific research areas that are poised for future development. Nearly all of these are encompassed within either the three focus initiatives of the commission or the department emphasis areas. While making no recommendation as to support of specific areas, the report emphasizes the speed with which science changes and the need for the University to be able to respond quickly and flexibly to future developments in science.

The School of Engineering and Applied Sciences

Quantum and Nanoscale Science and Technology

Over the past five years the School of Engineering and Applied Science has been building an interdisciplinary strength in quantum and nanoscale science and technology. This relatively new area of activity has its genesis within the school's established strengths of advanced materials, microelectronics, and information technology.

- The National Science Foundation has just awarded a five-year, \$5-million Materials Research Science and Engineering Center (MRSEC) to the engineering school for research, education, and outreach in the area of nanoscale self-assembly of semiconducting surfaces. This new Center for Nanoscopic Materials Design will be a nationally recognized center of excellence working at the forefront of the emerging nanotechnology field.
- The Defense Advanced Research Project Agency (DARPA) is currently funding a multiyear, multimillion-dollar Molecular Level Printing program within the departments of Materials Science and Engineering and Electrical Engineering. This project is developing novel methods of patterning both planar and curved substrates for applications in electronics and biology.
- Chemical Engineering and Materials Science and Engineering researchers are modeling the design of vapor deposition processes for engineering material growth on the atomic scale as part of a multiyear, multimillion-dollar initiative. The giant magnetoresistance materials under study are now used in all new computer disk drives. The modeling work is making possible the atomic level design of functional materials for use in many material systems.
- The Electrical Engineering and Materials Science and Engineering Departments have recently completed the hiring of six new tenured or tenure-track faculty members who are significantly bolstering the engineering school's strength in the design and fabrication of nanoscale materials and circuits. The combination of these new intellectual assets with the school's existing faculty should propel the school to new heights of recognized excellence in quantum and nanoscale science and technology.
- Further work in: aerogels, biosensor detectors, mechanical and aerospace engineering.

Advanced Materials

Based in the Materials Science and Engineering Department, advanced materials research within the engineering school is a multidisciplinary activity that reaches into chemical engineering, mechanical and aerospace engineering, and electrical engineering. Researchers

within this discipline seek to model, characterize, sense, and empirically study the behavior of metals, ceramics, polymers (plastics), and semiconducting materials.

- The engineering school has been awarded a \$5-million Materials Research Science and Engineering Center (MRSEC) by the National Science Foundation. This center expands upon the school's strengths in electronic materials, nanopatterning, and the vapor deposition of materials, and, over the next five years, its faculty will study the self-assembly of atoms onto semiconducting surfaces, contributing to important new advances in microelectronics, biological science, and telecommunications.
- Materials Science and Engineering and Electrical Engineering contain a set of outstanding materials characterization facilities. These include an atomic force microscope, a focused ion beam system, and multiple state-of-the-art transmission and scanning electron microscope systems. These facilities provide University faculty with the ability to probe materials at the most sophisticated level available today.
- The Intelligent Processing of Materials Laboratory within Materials Science and Engineering has just completed installation of a multimillion-dollar, second-generation directed vapor deposition system. This technology, patented by the University of Virginia, provides the engineering school with an unparalleled ability to synthesize multicomponent metal, ceramic, and semiconducting materials for fields as wide ranging as medicine, transportation, and microelectronics.
- The Center for Electrochemical Science and Engineering is built on the foundation of the Applied Electrochemistry Laboratories, a highly successful research unit established in 1974. In 1986, the Virginia Center for Innovative Technology identified the Center as a Technology Development Center. CESE is a multi-disciplinary research effort that includes activities in the Departments of Materials Science and Engineering, and Chemical Engineering, as well as interactions with Electrical Engineering, Computer Science, and Physics.

Technology in Medicine

The engineering school is collaborating with the School of Medicine and the College of Arts & Sciences to provide a teaching and research environment that advances medical engineering research and improves health care. In collaboration with partners from industry and government, the school is pursuing new capabilities such as gene therapy, noninvasive imaging, and cellular engineering that stand to revolutionize the treatment of disease.

- The engineering school's Virginia Artificial Heart Center designs, develops and tests a magnetic bearing-supported artificial heart for human implantation. Current work is on a ventricular assist version of the pump, but future work will be on a total heart replacement. In collaboration with the University of Utah, the center has recently won a \$4.2-million grant from NIH.
- The Biomedical Engineering Department recently received a \$3-million Development Award and a \$7.5-million Special Grant from the Whitaker Foundation. The

University of Virginia is utilizing the special grant to construct a Biomedical Engineering and Medical Science Building to house the expanded department.

- Biomedical Engineering and researchers at Northwestern University have just received a 3-year, \$3.5-million NIH grant for the project entitled “Biomechanics of Leukocyte Adhesion Molecules.”
- The National Institute of Diabetes and Digestive and Kidney Disease, a part of NIH, has pledged \$5.1 million over five years for the development of a cure for Crohn’s Disease, a disorder that causes inflammation in the intestines. Researchers within the Biomedical Engineering Department will work with School of Medicine scientists in the Digestive Health Research Center to attack this problem.
- The engineering school, in collaboration with the School of Medicine, has an NIH-funded Biotechnology Training Grant which provides interdisciplinary doctoral training in biotechnology through interactions with experienced investigators in the School of Medicine and in the School of Engineering and Applied Science. Research, education, and industry internship activities range from molecular biology and applied immunology to process scale cell culture, enzyme catalysis, and separation technologies.

Environmental Engineering and Management

The goal of this resource within the engineering school and the College of Arts & Sciences is to take a comprehensive, interdisciplinary view of environmental management, developing the technology and materials to enable government and industry to respond to these issues in a cost-effective and efficient way.

- Since 1993, the IBM Environmental Research Program has awarded over \$1.4 million to establish and build the Computational Laboratory for Environmental Biotechnology, devoted to the quantification, simulation, and design of in situ bioremediation processes—a powerful, cost-effective technology for restoring contaminated sites by exploiting the natural degradative and migratory abilities of bacteria
- The engineering school also has a Program for Interdisciplinary Research in Contaminant Hydrogeology through which Environmental Sciences, Chemical Engineering, and Civil Engineering graduate students can participate in an NSF supported Graduate Traineeship Program studying fundamental and applied problems associated with chemical contamination of the subsurface environment. This program has been supplemented with support from the university’s Academic Enhancement Program.
- The Environmentally Conscious Chemical Manufacturing Program within the Chemical Engineering Department has received support from NSF and the university’s Academic Enhancement Program. This program is engaged in groundbreak-

ing research to provide industry with cost-effective, nonpolluting alternatives to traditional catalysts and solvents.

- The engineering school's Center for Risk Management develops theory and methodology for the assessment of risk in a variety of civilian, defense, water resources, and other engineering systems. Applications of the center's work include: environmental impact, hazardous waste, groundwater; water resources, inland navigation, water distribution, and civil infrastructure.

Transportation Technology

Across its departments, the School of Engineering and Applied Science has a strong history of top-flight research into the multifaceted field of transportation. These activities span from materials research within Chemical Engineering and Materials Science, to automobile accident research within Mechanical and Aerospace Engineering, to traffic modeling in Civil Engineering, and to transportation safety within Electrical Engineering.

- The Automobile Safety Laboratory is an interdisciplinary program of the School of Engineering and Applied Science and the School of Medicine (through the Center for Prevention of Disease and Injury). Since the mid-1970s, this facility has been enthusiastically funded by industry and government sources for research in biomechanics, computational mechanics, and vehicle crashworthiness.
- Within the Civil Engineering Department, the engineering school houses the Center for Transportation Studies (CTS), an interdisciplinary program of research, education, and technology transfer that includes the Smart Travel Lab, a state-of-the-art facility which studies the rapidly emerging area of intelligent transportation systems (ITS). This lab uses continuously transmitted data and video from two of the Virginia Department of Transportation's (VDOT's) traffic control systems to provide researchers with realtime signal operation and loop detector data as well as archived data.
- Within the Chemical Engineering Department a set of faculty actively researches fuel cell, critical components in future power generation systems. The Materials Science and Engineering Department studies corrosion issues and coating systems for various segments of the transportation industry.
- The engineering school has recently established a Center for Safety-Critical Systems within the Electrical Engineering Department. Researchers within the center study the complex interactions among computers, physical systems, communications systems, and people. The center is currently working with the Federal Railroad Administration to develop a process for railroad system suppliers which will help demonstrate the safety of their products. The center also has a project underway with Boeing to build safety-critical considerations into that company's design process.

Microelectronics

Multi-investigator, interdisciplinary research, education, and industrial outreach activity in microelectronics is led by the University of Virginia Institute for Microelectronics (UVIM). With its base in the School of Engineering and Applied Science, UVIM reaches out to faculty in the College of Arts & Science and the Darden School to create an effective resource for the microelectronics community.

- Researchers within UVIM formed an important part of the core team which submitted a Materials Research Science and Engineering Center (MRSEC) proposal to the National Science Foundation. This proposal was just funded at a level of \$5 million over 5 years.
- UVIM faculty members worked together in 1999 to win a 3-year, \$0.5-million grant from the National Science Foundation for a Course, Curriculum, and Laboratory Improvement (CCLI) grant focused upon the creation of “Interactive, Multimedia Education Materials for Advanced High School and Early College Students.” Materials developed within this grant have added strong credibility to several major engineering school research proposals, demonstrating the school’s commitment to research *and* education.
- In close collaboration with industrial partner Dominion Semiconductor, UVIM faculty have created a Semiconductor Manufacturing Information Technology Center (SMITC). This center studies the gigabites of data produced during computer chip manufacture and identifies trends which affect the quality and yield of chips produced in multibillion dollar facilities like that at Dominion Semiconductor.
- UVIM has organized a University faculty discussion on “The Future of Microelectronics: Beyond Silicon.” This initiative was kicked off in the Spring of 2000 with a retreat attended by more than forty faculty. UVIM is now focusing this effort by organizing plans for a 2002 bid for an NSF-funded Science and Technology Center.

Within electrical engineering, researchers use the latest industry-standard circuit design tools to design and simulate cutting edge application specific integrated circuit designs. This expertise has recently led to the funding of a \$1.8-million, 3-year program for the study of novel infrared sensor systems with integrated data analysis circuits.

Information Technology

Faculty within Computer Science, Systems Engineering, and Electrical Engineering are bringing together a diverse set of capabilities to impact the development, modeling, and evaluation of information-based systems. These researchers design and build innovative distributed systems; use these to build larger integrated general-purpose or application-specific systems; and support the development of appropriate software and information systems to analyze the performance of these and other mainstream information-based sys-

tems.

- VINTLab, the Virginia Internet Engineering Laboratory, provides students with realistic, hands-on experience with networking hardware and software. The goal of the VINTLab effort is to graduate Internet Engineering who can maintain, update, improve and even redesign future incarnations of the Internet.
- Researchers have built a multi-computer, Centurion, that is composed of over 400 commercial, off-the-shelf processors capable of delivering 400 gigaflops peak performance. Legion is a companion software system that supports very large applications running on Centurion, or on geographically distributed, heterogeneous computers. Legion assures scalability, fault tolerance, security and site autonomy.
- The Departments of Computer Science and Electrical Engineering established a jointly administered B.S. degree program in computer engineering, which the state recently approved.
- Faculty in several departments explore solutions that will lead to more survivable information-intensive systems. We develop techniques to manage risk, assure code safety, and to analyze infrastructures and systems such as those for water, electric, railroad, transportation, law enforcement, and other safety-critical infrastructures.
- Sustaining intelligent human-computer interactions require new techniques such as the ability to animate synthetic characters in graphical environments, to use human gaze to guide what is processed and presented to the user, and to render very large geometric datasets.
- New services offer through databases, multimedia networks, and ubiquitous embedded computers pose fundamental engineering problems in the storage and retrieval of data, sustaining service quality, and integration of computation into functional objects.

The School of Medicine

Biomedical Imaging

This area represents a long-standing expertise at the University of Virginia, but with recent programmatic developments and recruitment of new faculty, this interdisciplinary program has achieved international excellence. The research and training programs involve faculty in many departments, including Biomedical Engineering, Radiology, Cardiovascular Medicine, the Cancer Center, TCV Surgery and Molecular Physiology and Biological Physics.

- Hyperpolarized gases (helium and xenon) are used for imaging the lungs of patients with chronic obstructive pulmonary disease and asthma, and may in the

future serve as the basis for therapeutic intervention. Recently, additional applications of this technology are being developed to image other locations in the body, such as the colon, sinuses and, in the future, it is expected that intravascular sites will be visualized by this method. The training element of this program reflects joint efforts of the Departments of Radiology, Physics, Biophysics and Biomedical Engineering. Two graduate trainees in this program were recipients of Young Investigator Awards for presentations in clinical and basic science at the 8th Annual Meeting of the International Society of Magnetic Resonance Medicine this year in Denver, Col.

- Dynamic cardiac MRI imaging is being developed with the objective of replacing the invasive procedures of cardiac catheterization to study defects in coronary circulation and other cardiac problems. New faculty have been recruited in Radiology and Cardiovascular Medicine, which has already achieved national and international prominence.
- Administration of microbubbles with their detection by ultrasound techniques has been developed into a very useful approach to imaging of the vasculature and measurement of intravascular flow. This technology from the Division of Cardiovascular Medicine in the Department of Medicine is now yielding exciting alternatives for drug delivery.
- Animal studies for evaluation of gene expression, anatomic defects and tumor development are conducted in the SAMRIS (Small Aperture MRI/Spectroscopy) Center as an early step in translational research. This facility is operated as a core laboratory of the School of Medicine and has users in many departments.
- An important part of the future for imaging at the University of Virginia is establishment of a program in functional MRI. This promising application of MR imaging will depend on recruitment of an investigator to head the program and purchase of additional equipment. The departments that will be involved in this activity include Psychiatric Medicine, Radiology, Neurology and Neurosurgery in the school of medicine and Psychology in Arts and Sciences.

Chromatin Regulation and Gene Expression

As part of a rebuilding effort, the Department of Biochemistry and Molecular Genetics has spearheaded an effort to establish an institutional center of excellence in nuclear structure and function. Together with several investigators in the Department of Microbiology, the University now ranks among the two or three best institutions in the world for studies on chromatin structure and regulation of gene expression. The recent recruitment of several outstanding young faculty members working in the areas of DNA replication, cell cycle control, and cancer, as well as structure/activity relationships in macromolecules that participate in these processes, has shaped a cohesive group of investigators working at the forefront of biological information utilization. These faculty members offer strong educational programs in the form of didactic courses, seminars, symposia and one-on-one student and postdoctoral training.

- At the core of these efforts are several distinguished research programs dedicated to an understanding of how DNA is packaged into chromatin and decorated with regulatory proteins that govern timely utilization of the underlying sequence information. Importantly, a new “chromatin code” has been discovered in which the basic histone proteins around which the DNA is wrapped are modified by acetylation, phosphorylation, or methylation to allow access to critical regulatory sequences by transcription, DNA replication, and repair complexes, and to facilitate attachment of chromosomes to the mitotic spindle.
- Modern molecular biology has focused attention on the macromolecular complexes that effect important transactions such as transcription, replication, and DNA repair. The structures of these complexes are too large and elaborate to be solved by standard X-ray diffraction or NMR techniques, and too small to be resolved by light microscopy. Researchers in the Department of Biochemistry and Molecular Genetics are in the forefront of high resolution image reconstruction techniques (on both conventional and cryo-preserved specimens) that bridge this gap in resolution. These approaches have contributed to an extremely detailed understanding of how helicases and recombination proteins interface with DNA to affect its structure. Similar techniques have been used to visualize the structure and dynamics of actin, which is the most abundant proteins in eukaryotic cells.
- It has become apparent in recent years that eukaryotic cells have elaborated extremely complex and finely-tuned regulatory processes that make sure that a cell does not enter the DNA synthetic or mitotic phases of the cell cycle if there are any breaks in the DNA template. The cell also knows not to begin cell division unless both members of each chromosome pair are accurately lined up on the mitotic spindle. Several research groups have contributed significantly to an understanding of how these signal transduction pathways function and how they are deranged in human cancer.
- With the completion of the human genome project and several other genome-wide sequencing projects, the need for sophisticated computational approaches to understand and integrate all of this information has dramatically increased. Investiga-

tors in the Department of Biochemistry and Molecular Genetics, as well as in Health Evaluation Services and Computer Science, have been leaders in the design of new paradigms for sequence comparison and analysis to understand basic problems in evolutionary biology, protein structure, and mutations that lead to human disease. A new Computational Genomics Center has been established in the Department of Biochemistry and Molecular Genetics, which will nucleate the University's efforts to remain in the forefront of this thoroughly modern and major new arm of biomedical science.

Immunologic Diseases

With leadership from the Beirne B. Carter Center for Immunology Research (BCC), many investigative and educational programs within the school of medicine involving immunologic disease and techniques have been strengthened and focused. These include scientists from the Departments of Biomedical Engineering, Medicine, Microbiology, Pathology, Pediatrics and Surgery.

- The Division of Rheumatology in the Department of Medicine was awarded a multimillion-dollar NIH SCOR grant on immunologic basis of systemic lupus erythematosus.
- An important focus of investigation in the BCC is the understanding of mechanisms of antigen recognition, signal transduction and regulation and tissue damage by T-cells. These immunologists from different departments provide a core of expertise for the immunology training program in the center and have established many fruitful collaborations.
- The Department of Biomedical Engineering is supported by the Whitaker Foundation and an NIH Bioengineering Partnership (jointly with Northwestern University) to study inflammation and the biomechanics of cell adhesion involving inflammatory cells. This program is an integral component of the immunology and cardiovascular research efforts of the institution.
- A major focus of work in the Division of Gastroenterology and Hepatology of the Department of Medicine is inflammatory bowel disease and the genetic and immunologic basis for these devastating disease processes. The division, with collaborators in biomedical engineering and pathology, was recently awarded a \$5-million program project grant to study the immunologic factors in Crohn's Disease.
- Investigators in the Department of Biochemistry and Molecular Genetics have developed a process to clear pathogens and foreign particles from the body using antibodies attached to human red blood cells. This work, with potential for application to many diseases and pathological states, has been funded by the NIH, the Department of Defense, and private industry over the past five years.

Cancer Center

Investigators in many departments of the School of Medicine participate in the programs of the NIH-funded Cancer Center to address problems of genetic risk of cancer, development and behavior of cancer cells in migration and cell-cell interactions, and identification of new modes of therapy and prevention.

- Basic studies of cancer cell behavior are historically the central focus of the University of Virginia Cancer Center. The center is supported by funding from NIH/NCI and the American Cancer Society, as well as other charitable foundations and individuals. The comprehensive cancer center grant and a specific cancer training grant fund a program in cancer cell biology with components for graduate students, post-doctoral fellows, and medical students.
- The Department of Health Evaluation Sciences has recently been funded by a grant from the Robert Wood Johnson Foundation to study genetic risk of cancer in the Charlottesville population.
- The Department of Urology operates an active and productive program in prostate cancer research with other scientists in the Cancer Center. This school of medicine program was recently the recipient of an award of \$20 million from the estate of Paul Mellon. This gift, one of the largest in university history, will provide support for new faculty and renewed interdisciplinary efforts to identify causes, prevention and treatment for prostate cancer.
- The Human Immune Therapy Center (HITC), which began with a focus on therapeutic vaccine for melanoma, has initiated clinical trials of such a product. In conjunction with other scientists in the Beirne B. Carter Center for Immunology Research, the staff of the HITC is now searching for antigens associated with other types of tumors for use in additional vaccines.
- Pilot funds have been recently obtained from the NIH for investigators in the Departments of Microbiology and Cell Biology to develop a multi-institutional program in cell migration. This important interdisciplinary area of expertise at the University has relevance to the fields of cancer metastasis, but also is fundamental to all of cell and developmental biology, a focus area for the commission.

Neurosciences

The aggregate of the Departments of Neuroscience, Neurology, Neurosurgery and Psychiatry in the school of medicine and the Departments of Biology and Psychology in the College of Arts & Sciences make up a collaborative training and research program in the neurosciences. This group operates a training program that is truly multidisciplinary.

- The Department of Neurology has both clinical and basic research expertise in neurodegenerative disorders, such as Parkinson's Disease and Alzheimer's Disease. An NIH-funded center based in the department provides funding for investigation

of the genetic mechanisms of transmission and pathogenesis, with evidence implicating mitochondrial DNA and defects in the production and clearance of oxidative radicals.

- In the Department of Neuroscience, special techniques have allowed development of a transgenic mouse in which expression of specific genes can be controlled *in vivo* by lactose. This novel genetic construct is being used to dissect the role of a number of molecular pathways during neuronal development and plasticity.
- Recently recruited faculty in the Department of Neuroscience, working with clinical and basic investigators in Neurology, will provide an enhanced program for study of Huntington's Disease, an important genetically transmitted, degenerative neurological disorder.
- Investigators in the Departments of Neurosurgery and Psychiatric Medicine and the Division of Endocrinology and Metabolism of the Department of Medicine are working on the relationships between the nervous and endocrine systems, through the regulation of pituitary hormones and systemically acting compounds. These programs reflect the important interface between affective and behavioral disorders and hormonal imbalances of a variety of origins.
- Investigators in the Departments of Neurology, Neuroscience and Neurosurgery are at the cutting edge of experimental and clinical studies characterizing mechanisms and novel therapeutic strategies for epilepsy, as well as internationally-recognized leaders in the understanding and treatment of stroke.

Appendix C:

Critiques by Consultants

Three consultants were asked to review the Science and Technology Commission report: Joseph M. Cronin, Donald Kennedy, and Polley McClure. A synthesis of their comments follows brief bios.

Joe Cronin is president of EDVISORS, an educational advisory service. Formerly president of Bentley College (1991-1997) and the Massachusetts Higher Education Assistance Corporation from 1980-1991, Mr. Cronin has been active in founding education loan companies and other loan and scholarship programs. He has taught at Harvard, Stanford, Boston College, and Boston University. From 1972-75 he served in the Massachusetts governor's cabinet as the first state Secretary of Educational Affairs and in Illinois as state Superintendent of Education from 1975-1980.

Donald Kennedy, a biologist by training, is Bing Professor of Environmental Science and president emeritus of Stanford University. He is also co-director of the Center for Environmental Science and Policy, an interdisciplinary center devoted to exploring how the natural and social sciences can contribute to improving environmental practices and institutions. In 1977, Dr. Kennedy served for two and one-half years as Commissioner of the U. S. Food and Drug Administration, returning to Stanford to become president for twelve years. He was elected to the National Academy of Sciences in 1972, and is also a member of the American Academy of Arts and Sciences and the American Philosophical Society.

Polley McClure is vice president for information technologies and professor of ecology and evolutionary biology at Cornell University. She previously taught environmental sciences at the University of Virginia and information resources and biology at Indiana University, Bloomington. Her more recent work has been in university leadership roles, managing and studying information technologies.

General Assessment and Approach

All three consultants found the report strategically sound and persuasive, impressive in building its case. In Cronin's words, the commission "boldly, dramatically describes a decade-or-more-[old] UVa action plan to raise the level of scientific research, biological and technology development. . . . The several strategies are interdisciplinary, transformational, fundable, and deliberately selective."

While all three approved the general strategy, they raised questions about the "centers of excellence" approach—building on faculty and departmental strength in areas of promise. Kennedy noted two potential areas of criticism: "(a) [that] UVa's strength is now not sufficient in the basic science departments to provide an adequate base on which to build or, alternatively, (b) that the Centers will simply deflect attention from the need to strengthen

the departments. The first of these propositions is self-testing, and I think it just has to be tested. The second surfaces an old tension: departments always fear that orthogonal structures will somehow damage them.” He sees this as basically “a complaint about the migration of labels and authority,” and the proposed change may well strengthen departments in the long run.

McClure is concerned that the University may be choosing its areas of focus without reference to its “relative comparative advantage.” For her, the question is “not merely ‘what are the hot areas going to be?’, but . . . ‘which hot areas would UVa have a special head start or advantage in pursuing?’ . . . If UVa really believes it can be a winner in these areas, I think a rationalization is needed in the report.”

Particular Strengths and Weaknesses

Cronin and Kennedy had special praise for “the centralization move” to a single provost and recommendation on graduate education. Cronin felt that there should have been more explicit detail in the budget assumption and a “much more methodical price-tagging of faculty lines, laboratory space and staff.” While all consultants noted that these recommendations budgeted an extraordinary amount of resources, which in some cases needed justification, Cronin pointed out that in some areas—e.g., Recommendation 4 (new faculty and lab costs)—the endowment predicated “may not be anywhere near enough.”