

# Graduate Education in Science and Engineering: A Time for Reassessment?

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My earliest association with Noel Corngold occurred during my graduate education at the California Institute of Technology in the mid-1960s. After a long and distinguished career at the Brookhaven National Laboratory, Noel had moved to California, initially to spend a year on the “start-up” faculty of the newly formed University of California at San Diego. The faculty offices were temporarily housed in the Scripps Institute of Oceanography, overlooking the Pacific Ocean. In 1966 he accepted a faculty position at Caltech, in faculty offices overlooking the smog covering the San Gabriel Mountains above Pasadena. He arrived at Caltech at about the same time that Bob Conn and I were launching our Ph.D. dissertation research.

Although my thesis advisor at Caltech was the late Harold Lurie, I had the good fortune to work with Noel during the final stages of my dissertation research. He encouraged me to continue to work with him for another year as an U. S. Atomic Energy Commission Postdoctoral Fellow on an array of topics in nonequilibrium statistical mechanics. I then accepted a faculty position in the Department of Nuclear Engineering at the University of Michigan.

Today my professional activities have drifted far from the intriguing world of mathematical physics and nuclear science. However, I remain actively involved in the policies governing graduate education and research through my roles in academic administration (university dean, provost, president) and national science policy (the National Science Board and the National Academy of Sciences).

My years of graduate study were brief, at least compared to the marathons many Ph.D. students are required to run these days, but it was one of the most intellectually stimulating and satisfying experiences of my career. This was due in significant measure to the influence of Noel Corngold. Since Noel Corngold had such a profound impact on my own experience in graduate education, it seemed appropriate to develop a paper on graduate education in honor of this aspect of his remarkable career.

Graduate students are expected to possess the intellectual maturity to determine their own course of study, to set their own pace. This results rapidly in a sense of personal responsibility and control that sets graduate study apart from the undergraduate experience. The ability to delve into a subject as deeply as one wishes is satisfying and rewarding—and unlikely to occur again in one’s later career.

Our current paradigm of graduate education is based on an important, yet fragile, relationship between the graduate student and the faculty that evolves from mentorship into collegiality. In the latter stages of their studies, many graduate students acquire knowledge in a narrow area that exceeds that of their faculty supervisor. At this point, the learning relationship changes from the master-apprentice nature of undergraduate education to the peer-to-peer relationship that characterizing collaborators and colleagues. Many faculty members will acknowledge that some of their closest friends were their graduate students. This is natural, since the bonds between the faculty and graduate

students are strong in almost every discipline. Faculty members and their graduate students work together and learn together.

Graduate education introduces students to diverse roles in the academy—students, teachers, scholars, and faculty colleagues. Graduate education can be a particularly enjoyable experience, since students can develop a true love of scholarship, drawing upon the reputation of their institution and their faculty mentors, without being subject to the other pressures of the academy such as grantsmanship or the achievement of tenure.

However, life as a graduate student is not without stresses, foremost among them being the concern about future employment. Like many of my faculty colleagues, my own graduate education occurred during the mid-1960s. While the post-Sputnik emphasis on science had attracted many of us into graduate studies, the Vietnam War and the end of the Apollo program brought a significant downturn in the job prospects for Ph.D.s. While the rumors of Ph.D.s driving taxicabs were a bit exaggerated, it nevertheless was a time of concern to new graduates.

It was a time much like today, when questions are being raised about the needs of our society for Ph.D.s and whether our doctorate programs are responsive both to graduate students and societal needs.

### A Time of Growing Concern

The current American system of graduate education evolved from an important public policy adopted following World War II in this nation. At the conclusion of World War II in 1945, a study group chaired by Vannevar Bush issued a seminal report, *Science, the Endless Frontier*. It proposed a partnership between the federal government and the American university aimed at the support and conduct of basic research and graduate education. “Since health, well-being, and security are proper concerns of government, scientific progress is, and must be, of vital interest to government.”<sup>1</sup> At the heart of this partnership was a recognition of the importance of free and open inquiry, an explicit integration of research and advanced training, and an emphasis on the importance of the scientific and technical workforce.

This partnership led to a new institutional form, the American research university. It has had an extraordinary impact both on our institutions and the society they serve. Federally supported academic research programs have greatly strengthened the scientific prestige and performance of American research universities. This academic research enterprise has played a critical role in the conduct of applied, mission-focused research in a host of areas including health care, agriculture, national defense, and economic development. It has also produced the well-trained scientists, engineers, and other professionals capable of applying this new knowledge.

It is not surprising that during these times of challenge and change in higher education, the nature and quality of graduate education has also come under scrutiny. Traditionally the faculty and their universities prefer to focus concerns on the adequacy and nature of the financial support for graduate education. Graduate students are more concerned with the job market for graduates and the time to obtain a degree. The federal government has expressed concerns about the number of advanced degrees relative to market needs and the high percentage of foreign graduate students.

But there are deeper and more troubling concerns. The current highly specialized form of graduate education may no longer respond to the needs both of our students and our society. Tragedies such as graduate student suicides and emotional instability suggest that the relationship between student and advisor may need to be re-examined. The increasing trend toward unionization of graduate student assistants on many of our larger university campuses suggests we may need to reconsider their broader role in our university teaching and research.

#### *The View of the Academy*

Recent studies both by the national academies and government agencies confirm a strong consensus that graduate education in America represents the world's leading effort for producing the next generation of researchers. By conducting graduate education in the same institutions where a large portion of the nation's basic research is done, our research universities have created a research and training system that is one of the nation's great strengths—and the envy of the rest of the world.

Most faculty members strongly believe that graduate education is essential to the research enterprise. It is through the process of graduate students working closely with faculty in collaborative research partnerships that we educate and train the next generation of teachers in how to create new knowledge. Some even suggest that the most important role of the federal government in graduate education is its support through research assistantships, since this provides the most direct link between education and research.<sup>2</sup>

But there seems to be a growing sense that it may be time to rethink the way we are preparing a generation of students whose career paths may look very different than did the career paths of their mentors. Related, but not identical, is concern for the employment dilemma facing graduate students and the need to revise graduate education in accordance with the current and future job market.

#### *Supply and Demand*

The American system of graduate education evolved when the demand for research was either stable or rising. The national security demands of the Cold War and domestic priorities such as health care and the environment stimulated federal support of the academic research infrastructure, which drove similar commitments to graduate education. This situation is now changing. The end

of the Cold War, the rapid growth of international competition in technology-based industries, and various constraints on research spending have altered the market for Ph.D.s. The three traditional areas of employment for Ph.D.s—universities, industry, and government—are all experiencing very significant changes which are likely to alter considerably their needs for individuals with research training. There is a growing concern that we need to re-examine the nature, capacity, and support of graduate education in America.<sup>3</sup>

Is there an oversupply of Ph.D.s? While unemployment rates for recent Ph.D.s have remained very low, there do seem to be far more seekers of faculty positions than there are available positions. There are also some worrisome indicators of weakness in the market, such as the substantially longer delays in the initial placement of new graduates. These signs suggest that the current oversupply of Ph.D.s—at least for the academy—will continue and may well worsen in the near term as federal budget cuts hit even harder.

There are already signs that in some fields the production of Ph.D.s far exceeds the availability of academic or research jobs. For example, the rapid growth in federal research funding in the life sciences over the past decade drove a corresponding increase in the number of Ph.D.s, far beyond that which could be accommodated by the academic market.<sup>4</sup> As a result, an increasing number of doctorates found themselves in temporary positions such as postdoctoral appointments or part-time faculty or research positions. More specifically, only about 60 percent of Ph.D.s in the life sciences have permanent positions six years after graduation. The average life scientist is likely to be thirty-five or forty before obtaining his or her first permanent job.

What about the impact of foreign graduate students on the market? The quality of America's graduate programs has long served as a strong magnet for attracting outstanding international students. In fact, over the past decade, most of the growth in the graduate student population in American universities has been a result of the growth in the number of foreign nationals enrolled in these programs. The enrollment of domestic students has remained relatively flat or even declined in some cases.

Because of the advanced, highly specialized nature of American graduate training, many of these foreign students have been unable to find employment that takes advantage of their newly learned skills in their home countries. As a result, a significant fraction of U. S.-educated foreign nationals attempts to enter the American job market. While the domestic employment of these students represents an extraordinary human resource for this country—and a significant brain drain from their home countries—they do intensify considerably the competition for the limited job market for faculty and research positions. So too, the disintegration of the Soviet Union and Eastern Bloc has triggered a mass exodus of talented scientists and engineers to the west. These have flooded the marketplace in many areas such as physics and mathematics.

Furthermore, the downsizing of the national defense effort, coupled with a reorientation of industrial research laboratories away from basic research toward

product research, has both reduced employment opportunities in the federal and industrial sector, while releasing into the marketplace scientists and engineers formerly employed in these areas.

*The Needs of the Broader Higher Education Enterprise*

There has also been concern expressed about the relationship between the current paradigm of graduate education in America's research universities and the broader needs of higher education. Last year, Robert Atwell, past president of the American Council of Education, used his final letter to the ACE membership to suggest that doctoral education, rather than the crown jewel of American higher education, may be at the root of many of our problems.<sup>5</sup> He suggested that the mismatch between doctoral education and the needs of the higher education marketplace is great. Too many faculty members in our research universities are out of touch with the mainstream of higher education—not to mention societal changes and fiscal realities. They go on trying to clone themselves in the persons of their graduate students to assist in their research. As a result, many new Ph.D.s who find jobs in non-research colleges become frustrated and often exert pressure on these institutions to become research universities—which implies, of course, offering Ph.D.s. Atwell contends that the research/graduate university paradigm has created a pecking order in American higher education that is out of touch with the needs of the nation and the academic marketplace.

For decades, the conventional wisdom has been that research and teaching are mutually reinforcing and should go together.<sup>6</sup> For example, in 1996 the National Science Board recommended in a major policy statement that

“The integration of research and education is in the national interest and should be a national objective. To advance this goal, federal science and engineering policies should strengthen efforts to promote the integration of research and education at all levels and should support innovative experiments in this area. Confidence that academic research enriches the educational process at U.S. colleges and universities underpins public support for science and engineering. Federal science and engineering policies should promote public awareness of model higher education institutions and programs that have demonstrated leadership in strengthening the synergy between research and education.”<sup>7</sup>

Even within the academy, doubts have been raised about the impact of the research university culture on education.<sup>8</sup> The fragmentation of disciplines driven in part by increasing specialization of scholarship has undermined the coherence of the undergraduate curriculum. There appears to be a growing gap between what faculty members like to teach and what undergraduate students need to learn.

*Disciplinary Specialization and Cloning*

Ph.D. students are expected to focus on a very narrow slice of disciplinary investigation in their studies and their dissertation. Although graduate students are expected to explore thoroughly and deeply a narrow intellectual area in their dissertation research, the hope is that in this process, they will acquire a powerful methodology for formulating and solving broader problems. In this sense, the purpose of doctoral education is to learn how to learn at a very sophisticated level. In a paradoxical sense, through such specialized inquiry, Ph.D. students acquire training that is well suited to broader investigation. Ironically, it is this specialist experience of the Ph.D. that provides training for a later role as an advanced generalist. Unfortunately, few Ph.D. students recognize this feature of graduate education, perhaps because few faculty members acknowledge or value it.

Many new Ph.D.s have far too narrow a set of personal and career expectations. They think that their graduate training has prepared them to solve certain highly technical and specialized problems. Of course, what they actually know that is of lasting value is how to formulate questions and partially answer them starting from powerful and fundamental points of view. Most do not understand that this is what gives them any edge they may have over young people of their own age who are already out in the workplace without Ph.D.s but with a several-year head start in experience.

Yet today's research problems are becoming increasingly complex, and their solution requires interdisciplinary teamwork. The training of new Ph.D.s currently is often too narrow intellectually, too campus centered, and certainly too long. The acceptance of overspecialization can result in a lack of both perspective and self-confidence. New Ph.D.s often believe themselves ill prepared to venture outside their specialty. This is due in part to the lack of serious requirements for breadth in the typical graduate curriculum. It is also due to the fact that there is little or no encouragement and a lot of implicit discouragement for one who wants to depart from the straight and narrow.

### *A Feudal System*

The success of the United States basic research endeavor has relied to a large extent on individual effort, as reflected in the investigator-initiated grant process. This emphasis on individuals is strongly reflected in the promotion and tenure system at research universities. It is also reflected in our approach to graduate education. Ph.D. training is best described as an apprenticeship. Graduate students are expected to attach themselves early and tightly to individual professors. In most universities, the faculty supervisor of a graduate dissertation becomes the primary determinant of the intellectual content, the duration, and the financing of the remaining education of the Ph.D. student, until the dissertation is written and the final dissertation defense is completed. In the best of circumstances, this final phase of graduate study can be very rewarding, since under the supervision of a skilled dissertation advisor, the graduate student learns the intricacies not only of basic research but also the trade of a faculty member. But this is also the point at which many of the problems arise.

Many faculty members have little experience in supervising graduate students, and abuses frequently occur. In some cases, faculty members are simply not adequately concerned about or attentive to a student's progress. In other cases they may even wish to prolong a student's studies so that he or she can continue to contribute to a key research project of the faculty member. There are also great differences in the nature of the relationship between graduate student and dissertation advisor among the disciplines. For example, in science and engineering, graduate students generally work side-by-side in the laboratory with faculty advisors, interacting with them almost on a daily basis. By way of contrast, in the humanities, it is not uncommon for a graduate student to meet with a dissertation advisor only a few times a year, clearly receiving very little guidance.

While the vast majority of faculty members regard the supervision of graduate students as both a significant privilege and sacred responsibility, there are inevitably cases of exploitation. Some faculty members adopt almost a feudal attitude, in which graduate students are regarded first and foremost as serfs to work on their research projects rather than as students seeking an education and a degree. As a result, some graduate students are seriously abused, required to perform menial tasks unrelated to their education, spending unnecessary years to get their degree, and tolerating the most excessive examples of faculty irresponsibility.

Little wonder students do not complain, since in most graduate programs, the faculty supervisor has ultimate control over the graduate student's ability to complete the degree and find employment. Universities have been extremely reluctant to interfere with this relationship between student and faculty supervisor, even when there is strong suspicion or possible evidence that significant mistreatment has occurred. Clearly there is a need to change the current model for graduate education, even if this encounters serious faculty resistance to keep the status quo.

### *Unionization*

The increasing trend toward unionization of graduate student assistants on the campuses of American universities is driven primarily by economic issues and power relationships. But it may stem in part from the abuse of graduate students that all too frequently occurs in our feudal culture of graduate education in which a single faculty member has complete authority over the academic progress, the career, and even the quality of life of a graduate student. Today sixteen of our largest university campuses have graduate student teaching assistant unions, including the Universities of Wisconsin and Michigan. The massive University of California system is facing a major confrontation with graduate students as they attempt to have their union recognized.

Such efforts may not be in the best interests of students, however. Most faculty members are intensely loyal to their graduate students, guiding their research and professional development, and frequently securing grant funding to support their tuition payments, their living expenses, and their research activities. The



faculty works hard to obtain funding for graduate education and pushes hard to make this a high priority for support by the university. Unfortunately, unionization brings both new participants and a new culture into what should be a mutually beneficial and supporting relationship between the faculty and the graduate students. The union leadership negotiates the status of the graduate students directly with the university administration within the framework of collective bargaining. Ironically, both faculty and graduate students give up one of the most cherished values of the university, academic freedom, since everything can end up on the table during such negotiations—not just compensation and benefits, but also academic matters such as course structure, class size, and the selection of graduate students for teaching assignments. The confrontational nature of labor-management bargaining is orthogonal to the collegial, learning-centered relationship that should exist between graduate students and the faculty.

While unionization may be the wrong approach to addressing either the issues of graduate student welfare or faculty responsibility, it is important that we understand that this movement in part reflects the need for real changes in the nature of graduate education. The faculties of our graduate schools have a responsibility to face the shortcomings of our current graduate education paradigm, which all too frequently tolerates serious graduate student abuse at the hands of insensitive or irresponsible faculty supervisors. They need to understand and address the growing chasm between the education of graduate students and the contemporary university's increasing dependence on their labor as teaching and research assistants. To fail to recognize and address these shortcomings of the current feudal system of graduate education will damage it just as surely as imposing on it the alien culture of collective bargaining.

### *Postdoctoral Education*

Of course, graduate education does not end with the Ph.D. In many fields, an appointment as a postdoctoral fellow in a university research laboratory has become not only commonplace but effectively a requirement for a later academic position. To be sure, there are strong intellectual reasons for postdoctoral appointments in some fields. Perhaps this level of advanced training and specialization simply cannot be achieved within a conventional Ph.D. program. Or an individual may need the experience of working with a senior scientist to learn not only advanced research techniques but also the ropes of grantsmanship. Postdoctoral appointments also allow young scholars to accumulate the publication record necessary for a more permanent appointment.

There are other reasons for the rapid increase in postdoctoral appointments seen in many fields over the past two decades—from 16,829 in 1975 to 35,379 in 1995. We have already noted that in some fields such as the life sciences there is a current glut of Ph.D. production. As a result, although postdocs are supposed to be temporary, they have become a holding pattern for many young Ph.D.s who are unable to find permanent jobs in research or who need more time to assemble the kind of publishing record that such jobs now require. This leads to what one scientist has called “the Laguardia effect, in which many recent graduates are

circling in postdoctoral positions, burning up very important and useful intellectual fuel, and waiting for their turn to land in a permanent academic or research position.”<sup>9</sup>

More significant, perhaps, is the role postdoctoral fellows play in the research enterprise. Unlike graduate students, postdocs have the sophistication to be highly productive in the laboratory or in a research group of senior scientists. They are highly motivated and work extremely hard, since they realize that their performance as a postdoc may be critical in attaining the faculty references necessary for further employment. And they are cheap, typically working at only a small fraction (20 to 30 percent) of the salary of a faculty member or research scientist. In fact, since most postdocs are not assessed tuition for their advanced training, in many institutions postdoctoral appointments are less expensive to support than graduate students.

Hence, it is not surprising that in many fields, the postdoctoral student has become the backbone of the research enterprise. In fact, one might even cynically regard postdocs as the migrant workers of the research industry, since they are sometimes forced to shift from project to project, postdoc to postdoc appointment, even institution to institution, before they find a permanent position. And, as with graduate students, they are all too frequently at the mercy of their faculty supervisor, with little university oversight or protection.

Most institutions make little effort to control the number or quality of postdocs, since these are identified, recruited, and supported through the efforts of individual faculty. (In fact, in recent surveys, some institutions did not even know the number of postdocs on their campuses.) There are few institutional policies governing postdocs, such as compensation or benefit policies or time limits on appointments. Few institutions have job placement services for postdocs, aside from the efforts of their faculty supervisors. The lack of institutional oversight of postdocs, coupled with the evolution of postdoc education in a number of disciplines into a virtual requirement for a tenure-track faculty appointment, has created an unacceptable degree of variability and instability in this aspect of the academic enterprise.

## The Fundamental Questions

The key issues swirling about graduate education can be summarized in a series of questions. First, what is the purpose of graduate education? Is it to produce the future researchers needed by our nation? Clearly, the current system of graduate education does this quite well. What about the role of graduate education in producing the future faculty needed by higher education? Some suggest that the current graduate education paradigm of the research university does not serve the majority of colleges and universities, which place far more emphasis on teaching than research. And what about the production of the next generation of scientists, engineers, and other disciplinary specialists? Or providing the educational background needed for other key professions in areas such as medicine, business, and law? There is a sense that an increasing number

of students with advanced training in science and engineering are moving into other professional careers such as medicine, law, and business. Should our graduate programs be responsive to this?

Beyond the production of human resources, what role should graduate studies play in providing the labor necessary to sustain the research university through graduate research or teaching assistantships? Unfortunately, the size of many graduate programs in science and engineering seems to be determined less by national need or employability than by the graduate assistant needs of local research projects or instructional programs.

The majority of Ph.D. programs have traditionally seen their role as training the next generation of academicians, that is, self-replication. The process of graduate education is highly effective in preparing students whose careers will focus on academic research. But more than half of new Ph.D.s will find work in non-academic, non-research settings, and our graduate programs must prepare them for these broadened roles. Most academic positions will be in colleges and universities that do not stress research. As a result, many new Ph.D.s who do find jobs in non-research colleges become frustrated and often pressure these institutions toward more research and possibly even the establishment of more graduate programs.

Second, just how appropriate is the current graduate education paradigm for the broader range of careers available to graduates? The current graduate education paradigm can be characterized best as an apprenticeship (although some graduate students would suggest more of a feudal system of indentured servitude) in which the dissertation advisor has significant responsibility for not only the content but the duration of the program. The current system, stressing specialization and depth of investigation, is frequently accused of cloning the current cadre of research faculty. In particular, the specialized training provided their graduate students leaves them ill-prepared for the broader teaching responsibilities of colleges primarily focused on undergraduate education.

Third, what is the best way to fund graduate education? The research assistantship is clearly the preference from the faculty perspective, since it provides the principal investigator maximum control over graduate students. Yet, one might well argue that the fundamental purpose of graduate research assistantships should not be to provide cheap labor for research projects but to support graduate education.

The graduate fellowship has been the traditional alternative to research assistantships, although there have been concerns. These include whether graduate fellows are too disconnected from the research interests of faculty and whether the portable nature of these fellowships tends to benefit the most prestigious institutions (not to mention those with warm climates).

An interesting alternative is provided by the graduate traineeship. Here the principal distinction between *traineeships* and *fellowships* is that traineeship grants are made to university programs and departments for a specified purpose or

program and then assigned to graduate students by the institutions. While traineeships have not been a major component of the portfolio in science and the humanities, they have been the dominant form of graduate student support in other areas, such as the health sciences, since they can allow a more carefully designed graduate experience.

Finally, what is the relationship of graduate education in research universities to the rest of the higher education enterprise? There is a sense among many that the research university—where most graduate education is conducted—is becoming increasingly detached from the rapidly changing higher education enterprise both in this country and abroad. In the past these universities have provided not only most of the faculty but most of the pedagogical models and curriculum content for higher education in America. Today, the relevance of the research university paradigm to the learning needs of our society is being seriously questioned.

## An Agenda for Action

To address these challenges, we need to consider possible actions at various levels: the graduate department or program, the university, and the national level of the higher education establishment.

### *The Department Level*

Actions at the department or program level are likely to be most effective in responding to the challenges to graduate education. Although the issues of graduate program size and Ph.D. production are important, these are not generally issues addressed at the department level. Nor are the basic policies and regulations governing graduate education determined at this level. Rather, it is the culture of graduate education, determined primarily by the relationships between graduate students and the faculty, that is most directly influenced at this level.

It is at the department level that one needs to examine seriously the feudal system that has evolved over the years. In particular, departments—and department chairs—must accept far greater responsibility for protecting the interests of graduate students in their relationships with faculty members in their roles as dissertation chairs, research project directors, or instructional supervisors. Such relationships are rarely reviewed in the traditional culture unless formal grievances are filed. This must be replaced by a culture in which department faculties as a whole accept more responsibility for the welfare of the student. A student's progress should be the responsibility of the entire department or program and not under the control of a single faculty advisor. The quality and character of faculty supervision of graduate students should be assessed on a regular basis. In those rare cases where abuse occurs, either because of faculty inexperience or temperament, there should be no hesitation in withdrawing the privileges of graduate supervision. New faculty members and

graduate students should be educated concerning their rights and responsibilities in graduate education.

Departments should review carefully the degree to which the size of their graduate programs is determined by faculty capacity and employment opportunities, rather than by the need for graduate teaching and research assistants to meet instructional and research needs. Departments should be challenged to develop alternatives to graduate students to meet these needs, such as the use of adjunct faculty to assist in teaching or permanent research scientists to meet the needs of research projects. The primary objective of graduate education should be the education of students. The value of activities such as working as research assistants or teaching assistants should be judged according to the extent that they contribute to a student's education.

Departments should be far more involved in providing both information about career opportunities and placement assistance to graduate students. While many faculty already participate in efforts to place their Ph.D. graduates, there should be a broader acceptance of responsibility for placing graduates. Indeed, this might be one way to stress the importance of aligning Ph.D. training with society's needs. Graduate students should certainly receive more up-to-date and accurate information about career opportunities. This should not only be provided directly by the graduate program or department, but academic units should consider assigning a faculty member as an ombudsman for graduate placement. Perhaps each faculty member who accepts the responsibility of the chair of a dissertation committee should also be asked to accept personal responsibility for the placement of the Ph.D. student!

Most important—and most difficult—of all is to get the faculty to change both the values and expectations they pass along to their graduate students. The current system tends to replicate itself by producing graduates trained for increasingly narrow—and increasingly limited—academic and research roles, largely ignoring the broader interests of our best students, the increasing diversity of today's generation of students, and the complex and rapidly broadening roles in our society played by those with advanced degrees. The world of the 21st Century will be far different than that for which today's faculty members prepared during their own graduate studies. It will require far greater breadth in scholarship, a deeper commitment to teaching and service, and far greater adaptability.

#### *The Institutional Level*

At the university level, there is clearly a need to encourage a broadening in Ph.D. requirements. While we must retain the paradigm of research training that is the acknowledged strength of the current system, we must also implement changes if our academic institutions and their graduates are to make their optimal contribution to society. We need to develop doctoral programs that emphasize disciplines at the borders between fields, as well as programs that include interaction among scholars within different disciplines. Careful attention will need to be given to striking the right balance between training individuals

capable of spanning fields and those with deep understanding of a highly specialized field. In a sense, we might well redefine the Ph.D. as the graduate analog of a “liberal education,” shifting it away from the cloning of the academy, and instead designing it to prepare an individual for a lifetime of learning.

It also seems clear that a greater number of job opportunities will be available to Ph.D.s who have experience and connections beyond the campus. To produce more versatile graduates, programs should provide options that allow students to gain a wider variety of skills. They should be discouraged from overspecializing. To this end, it is important that students be given a far more realistic perspective on the hiring market. In particular, they should have a better understanding of the kinds of experiences and training that non-research institutions seek in their new faculty.

It is also important in some fields that universities develop integrative, practice-oriented degree programs that better respond to the needs of industry, perhaps through a redefinition of the master’s degree or an alternative form of the doctorate. There has been strong interest expressed at the national level in making available internship experiences to graduate students.<sup>10</sup> Some have suggested that every graduate student should have the opportunity to spend time in an appropriate setting outside the university. Internship programs that provide students with experience in industry, government, or different types of academic institutions could prove useful in achieving the objective of broadening graduate education. In fact, one might even consider teaching internships, in which doctoral students interested in academic careers spend a period on the campus of a different type of educational institution—perhaps a liberal arts college or a community college.

Yet another challenge at the university level is reducing the time to degree. The time required for the Ph.D. has steadily increased for the past several decades, doubling in some cases to over ten years. Universities, their graduate programs, and their faculty simply must accept the responsibility of reducing the time to degree. There have even been suggestions of a radically different approach, based on programs that established a fixed-time-to-degree. For example, one might imagine all students beginning with a one-to-two year M.S. program, that might also serve as a terminal degree for those interested in other professional careers such as law, business, or medicine. The Ph.D. itself would require two additional years of study including a dissertation (or a total of four years, including the M.S. degree) and suffice for most advanced positions in the public or private sector. Finally, for those students interested in careers in either the academy or basic research, further study beyond the Ph.D. would be achieved through postdoctoral studies. These studies would provide the highly specialized training needed to move to the cutting edge of research.<sup>11</sup>

Such a dramatic change as accepting a fixed time to degree is highly controversial within the academy. The usual response is that there will always be considerable variation from individual to individual and program to program in the time required to master a field and produce original research. Of course, one might also make the same argument about professional education in

complex areas such as medicine, which long ago accepted fixed-period educational models. Perhaps instead of debating the issue, several graduate programs actually should try to develop Ph.D. programs with fixed terms for study and then let the graduate student and employer market decide which is more appropriate and attractive.

### *The National Level*

It has become increasingly clear that the forces within the university driving the production of Ph.D.s are decoupled from the marketplace. More specifically, there is little relationship between the supply of Ph.D.s and the demand for them. There are few internal or external incentives for graduate programs to reduce Ph.D. production. In most universities, the size of the Ph.D. programs and the consequent production of doctorates are driven primarily by the need for university teaching and research assistants. In science in particular, Ph.D. production is driven primarily by the level of research funding and not the needs of the society.

Rapidly reducing the size of graduate programs in those areas experiencing an oversupply of doctorates could prove disruptive to the research enterprise, but there are already calls for restraint in further growth of graduate education in some fields such as the life sciences. This will be difficult, since as long as federal funds for research continue to flow to departments, there will be pressure to expand Ph.D. production. Nevertheless, universities and federal agencies should work together to achieve a better balance between the size of graduate programs and the availability of employment opportunities.

There does not appear to be a compelling case for draconian limitations on foreign student enrollments in our graduate programs. Foreign Ph.D. graduates remaining in this country make significant contributions to the national interest. Further, there is already some indication that the rapidly evolving economies in those nations sending the largest numbers of students to American universities are beginning to create major growth in job opportunities. As a consequence many foreign national doctorates, both new and experienced, are beginning to return to their home countries.

The way that we support graduate education has been of particular concern. The current research-driven paradigm tends to view graduate education as either a byproduct activity, driven by the level of research funding, or as a source of cheap labor for research projects. Graduate students supported through research assistantships are forced to work on problems necessary for their advisor's research project but all too frequently unrelated to their dissertation topic. There are no incentives to reduce time to degree, particularly if the graduate student is making valuable contributions to the research project. Nor is there generally an opportunity for the student to elect other courses or experiences to widen their horizons.

There is a need for a better balance among research assistantships, teaching assistantships, fellowships, and traineeships in the support of graduate

education. To foster versatility, there should be broadening of the mechanisms for the federal support of graduate students. The shift from portable fellowships and traineeships to the research assistantship as the predominant method of graduate student support in the early 1970s created a situation in which training is driven primarily by the needs of sponsored research projects. Perhaps a more balanced effort, utilizing training grants, fellowships, and research assistantships, would allow more flexibility in graduate education. The National Institutes of Health have long used well-designed training grant programs to stress the development and support of graduate education in key areas. This paradigm should probably be used more frequently in other areas of graduate study. The government should also look to increase the number of federal agencies that provide substantial training dollars, which would have the benefit of diversifying the nature of Ph.D. training.

The federal government can have a major impact on concerns such as time-to-degree by imbedding appropriate incentives in the peer review process indexed to the average time-to-degree experience of the academic program submitting the proposal. There needs to be a recognition that the support of graduate education should be the responsibility of all federal agencies that utilize research and employ individuals with advanced degrees.

## Concluding Remarks

The research university has been extraordinarily successful in meeting the needs of our society for research and well-trained scientists and engineers during the past half-century. Yet today many of those needs have changed, and the role of the research university and the character of its activities in graduate education are being questioned.

Since federal policies played a key role in stimulating the evolution of the American research university in the decades following World War II, it is reasonable to expect there is an appropriate role for government in addressing some of the concerns about graduate education. There seems little doubt that the prosperity, security, and social well-being of our nation will continue to require an adequate supply of graduates with advanced degrees. It is therefore alarming to note that the United States has not had a definitive, coherent policy for human resource development related to graduate education for decades—since the massive efforts represented by the G.I. Bill in the 1940s and the National Defense Education Act in 1960s. Instead, the nation has drifted on autopilot, with its human resource development largely determined as a byproduct of federal research and development programs rather than through a strategic consideration of national needs.

It seems imperative that the nation develop both a vision and a closely aligned federal policy concerning graduate education capable of responding to the contemporary and future needs of the nation.<sup>12</sup> This policy should be closely coordinated with parallel policies concerning research and technology development and deployment. It should be executed through federal programs



that are sustained for a period sufficient to yield the necessary changes in the academic culture and to broaden the roles that those with graduate training will play in our knowledge-driven society. This policy should also respond to the changing nature of national needs and to the increasing diversity of the American people.

While there is a general consensus that the quality of graduate education in America has been second to none, there are signs of strain that will only increase with time. It is time that the faculty, our universities, and our national leadership in science and engineering step up to the challenge and responsibility of developing a new set of policies, guidelines, and practices appropriate both for graduate education and for serving the changing needs of society in a new century.

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<sup>1</sup> Bush, Vannevar, *Science, the Endless Frontier*, A Report to the President on a Program for Postwar Scientific Research, Office of Scientific Research and Development, July, 1945

<sup>2</sup> GUIRR

<sup>3</sup> National Science Board, *The Federal Role in Science and Engineering Graduate and Postdoctoral Education*, National Science Foundation NSF 97-235 (1998)

<sup>4</sup> Shirley Tilghman, chair, *Trends in the Early Careers of Life Scientists*, National Research Council (National Academy Press, Washington, D.C., 1998)

<sup>5</sup> Atwell, Robert,

<sup>6</sup> Peliken, Jaroslav, *The Idea of the University: A Reexamination* (Yale University Press, New Haven, 1992) 238 pp.

<sup>7</sup> Preface, *Science and Engineering Indicators 1996*, National Science Board (National Science Foundation, Washington, 1996)

<sup>8</sup> Shapiro, Harold T., "The Functions and Resources of the American University of the Twenty-First Century" (University of Chicago Symposium, 1991) Shapiro, Harold T., "The Functions and Resources of the American University of the Twenty-First Century" (University of Chicago Symposium, 1991)

<sup>9</sup> Shirley Tilghman, chair, *Trends in the Early Careers of Life Scientists*, National Research Council (National Academy Press, Washington, D.C., 1998)

<sup>10</sup> National Science Board, *The Federal Role in Science and Engineering Graduate and Postdoctoral Education*, National Science Foundation NSF 97-235 (1998) National Science Board, *The Federal Role in Science and Engineering Graduate and Postdoctoral Education*, National Science Foundation NSF 97-235 (1998)

<sup>11</sup> Graduate Education, Committee on Science, Engineering, and Public Policy, National Academy of Sciences (National Academy Press, Washington, D.C., 1995)

<sup>12</sup> M. R. C. Greenwood, chair, *Science in the National Interest*, Office of Science and Technology Policy (U. S. Government, 1996)