The Research University of the Twenty-First Century

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Changes affecting American research universities include rapid advances in information technology; trends in job requirements, career paths and demographics; business restructuring; and the use of societal benefit as a criterion for financing research. In response, research will become more collaborative and international. Scholarly communication will transformed by the electronic world. Libraries will become sophisticated linked information networks equipped with powerful search engines. The structure and size of the research enterprise will adapt to economic conditions. Research universities will build greater synergies between research and education and adjust to serve the needs of a diverse populace for primary and continuing education.

I much appreciate your invitation to join you today and to keynote this annual meeting. As a chemical engineer dealing in separations and as a former dean of a college of chemistry, I have long admired The Electrochemical Society for its focus on a vital and critically important interdisciplinary field. And as a chemical engineer turned university leader, I value greatly the contributions of the research enterprise to society. As well, I appreciate the intricate and necessary coupling of the academy, the business world and government within that enterprise. Hence I commend you for your special Symposium on Government, Academic and Industrial Interactions in the New Global Economic Environment, and I look forward to taking part in it today.

There is a bit of personal history that is meaningful to me as well, in that my father taught for a number of years just before World War II in the Department of Chemistry and Electricity at West Point. Probably that was the only academic department ever to reflect that combination, and perhaps it was a precursor of the interests that reflect themselves in The Electrochemical Society today.

Universities have often been noted for their stability. They are among our oldest and most venerable institutions. A speaker from the University of California must, of course, make the obligatory quote from Clark Kerr, and mine will be his observation that there are 70 institutions in the Western World that have been in continuous existence since the Reformation. Of these, two are the Catholic and Lutheran churches. Another two are the parliaments of Iceland and the Isle of Man. And the remaining 66 are colleges and universities. Thus we academics have a remarkable degree of permanence, stability and perseverance. Or perhaps you would like to characterize it as inflexibility, intractability and ossification.

But I will argue that it is the former, and not the latter. One of the reasons for our longevity as universities is that we have been able to change and adapt to the times. One need only look at the transformation of research universities over the last fifty years to see that. Nonetheless, there are today a number of voices that say we are unable to change. But change we have, and change we will.

As we emerge from the 1900s into the twenty-first century there are powerful evolutionary forces taking place in the nation and world. These changes present major challenges to our research universities, but they also generate great opportunities. How universities should respond to these changes is an interesting question in the abstract. And it has been made all the more immediate for the University of California by the fact that we are planning for a tenth campus in the Central Valley of California, to be located near the city of Merced, often denoted as the Gateway to Yosemite. The Merced campus should itself be the first major new US research university of the new century. So we at the University of California not only have to seek a clear vision of the future, but also have to put some very concrete (or brick, or steel and slate) realities in place to bear out that vision.

Of course, we can see only so far ahead, and even that imperfectly since no one can foretell the actual path of change. We have examples of the limits of foresight from our own lifetimes. I recall the start of my own career, some forty years ago, when, as a student in MIT's Oak Ridge School of Chemical Engineering Practice, I took a crash full-time course for several weeks learning very rudimentary programming for an early computer known as the ORACLE, which stood for Oak Ridge Automatic Computing and Logic Engine, or something close to that. Find a number in memory; bring it into the register; find another number elsewhere in the memory; bring it into the register as well; add the two numbers; and put the resultant sum back into a designated spot in memory. That was how we programmed a simple addition. In those days we could not begin to see where the advances in information technology — racing ahead and driven by Moore's Law — would take us over the four decades that have brought us to today.

We look ahead only imperfectly and with dim vision. But it is a more tractable task to identify what seem to be the most profound changes of the past few years and the present, and to make an extrapolation a few years and even decades into the future. That is what I would like to do today. So, the title of this talk might better have been "The Research University as We Enter the Twenty-First Century" or, somewhat more boldly, "The Research University in the first Decade or Two of the Twenty-First Century."

Changes

The next slide shows the areas where major changes are occurring. These are:

- the onslaught of information technology;
- jobs, career paths, demography and education;
- the business world and, within it, world business; and
- the financing of research and the judgement of its worth.

The Onslaught of Information Technology

As I have already suggested, the single most powerful change of our times is the rapid march, or better the sustained sprint, of the capabilities of information technology. Both the rate and magnitude of this change are truly awe-inspiring.

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Editor's Note: C. Judson King delivered the Plenary Lecture at the ECS Spring Meeting in San Diego this past May. His presentation is reproduced here with the kind permission of the speaker.

We have desktop computers that far exceed the capabilities of the mainframes of a few decades ago. We have the Internet and are now building new generations of it. We are increasing bandwidth by orders of magnitude. We can reach any point in the world and receive responses within seconds or a very few minutes. We can rapidly find and download any information that is in accessible electronic form. Moore's Law, named after Intel co-founder Gordon Moore and himself an electrochemist of sorts, says that computing power doubles every 18 months. That "law" is still in effect and will be so well into the new century. And there is no real reason to doubt that the next waves of discovery and technology will develop in ways that enable Moore's Law, or something much like it, to continue beyond what is presently known to be feasible. We are entering a world of very high-bandwidth communication throughout the entire world, in ways that fully overcome the previous limitations of distance, time, time zone and language. We are also on the threshold of major advances in man-machine interactions and synergy, such that man and machine will be able to act together in a much more unified fashion. You wink, and your computer responds!

Turning now more directly to the world of universities and education, we have seen in recent times the rise and growing success of televised and Internet-based instruction. Of course, these new activities cover the entire spectrum of quality that can be expected of such an unregulated enterprise. Institutions like the University of Phoenix, bring close-to-the-freeway pragmatic education to all comers. And, led by the very successful example of Britain's Open University, we are seeing so-called Virtual Universities sprout up in many forms. One of them is here in California, and the University of California is an active partner in it.

Jobs, Career Paths, Demography and Education

The rapid march of information technology in all aspects of our lives means that college education and technological literacy will be prerequisites for a higher and higher fraction of available jobs. More and more, education will be the determinant between the haves and the have-nots. The spread in quality of life between the educated and the uneducated has been increasing and will continue to do so. This fact couples with the growing ethic diversification of the American people, and it means that it is absolutely essential that we increase the availability and attractiveness of higher education to those who have participated in it at low rates, whether for reasons of culture and tradition, or because of the lack of availability of quality preparatory education, or economic reasons or other causes.

Historically, university education has been the primary route of upward social and economic mobility in America. It will continue to be that and will be it all the more. As we enter the new century this upward-mobility role of the universities becomes an absolute necessity. It must be fostered and sustained.

Another trend of the times is for people to shift careers at several points during their working lifetimes. As a result, there is a growing demand for continuing education — lifelong learning, if you will. The needs are for continuing education of all sorts, ranging from explicit, pragmatic courses to full-fledged advanced degrees in entirely different fields.

The Business World and World Business

Business has become global and highly interrelated among nations. Corporations and their suppliers and consumers operate in many different countries.

It is not unusual for a company to have research and development in one or two countries, manufacture in other countries, purchase components from still other countries, and distribute products in these and many other countries. The recent Asian financial crisis has demonstrated the interdependence of world economies and businesses.

Another trend that has taken place for some time in the business world is for business decisions to be guided by immediate payoff. Stockholder satisfaction has become a dominant concern, by virtue of the influence of very large portfolios, including, interestingly enough, university retirement funds. The trend for maximizing tomorrow's bottom line has led to a wind-down, or at least a shortening of the time horizon, for corporate research in many industries. At the same time, industrial sponsorship of research at universities and national laboratories has greatly increased, driven by hopes that such relationships can provide benefits that compensate for the changes in corporate R & D.

Financing Research and Judging Its Worth

The age of great expansion in federal support of research has ended. This is not because the public and Congress have lost interest in research. They may not understand it, but they still value it. But the organism was growing at a rate that could not be sustained. Vannevar Bush convinced us of the inherent economical and societal benefits of undesignated fundamental research. That paradigm has lasted half a century and has led to the impressive American research enterprise that exists today.

But the situation of implicit trust in the worth of research to the economy and society has now changed toward one where Congress and the public seek convincing assurance of the worth of research to society, in return for the commitment of public funds. And it is appropriate that they do so, as long as their management of the enterprise is macro rather than micro.

Over the same time, a body of research has grown up that documents the effects of research on the economy. Edwin Mansfield and his colleagues in this field have demonstrated that over half of the growth in per capita income in the United States in the decades since World War II is directly attributable to advances in technology.

They have also shown that research, as a whole, in the United States has produced a strikingly high annual return on investment — 20% to the organization that invests in the research, 50% to society and the nation at large, and a still greater rate of return for global society as a whole. The increases in the return going from the investor to the nation to the world are striking. They result from the fact that many of the benefits of more fundamental research accrue through subsequent developments and through uses of the results of the research by those who did not invest directly in the research. Such is the universally beneficial effect of the general growth of knowledge.

These figures on economic returns from research are of course weighted by industrial research, but the same set of studies has shown that the annual return from academic research is at least 20%, and probably substantially higher. The uncertainty comes from the difficulty of to estimating the entire scope of impact of a particular basic research result, and the often long time lags until societal benefits are actually realized.

How Research and Research Universities Will Evolve in Response to Change

OK, so that is an outline of some of the larger changes affecting research universities. Now, how will universities themselves change in response?

There are six general categories that I will cover. They are:

- the nature of research
- scholarly communication
- the information base for research
- the structure of the research enterprise
- the size of the research enterprise
- education in research universities

The Nature of Research

Let's start with the nature of research itself. Except in a few fields such as high-energy physics, academic research in science and engineering has traditionally been a matter of individual faculty members working with their research groups, composed of graduate students and postdoctoral scholars.

Several factors are bringing about much more collaboration among professors in different departments, in different institutions and even in different countries. There are several reasons for this. First of all, many of the most fertile areas for research are now multi-disciplinary, calling for the blending of complementary approaches from senior researchers from different disciplines. Second, the advances that have occurred and will continue to take place in information technology make distances, language, and differing time zones much less of an impediment than they have been. Collaborations among researchers in different countries can now be much more interactive and much more efficient. In some fields, and particularly in industrial research and development, advances can be made all the more quickly because research can follow the sun as the world turns, making sequential use of persons and facilities in different locations. For a researcher in a given location, much can happen elsewhere between the end of the day and the beginning of the next day.

A side benefit of the growth of international collaborations will be that graduate students and postdoctoral scholars will spend some of their time in other countries. Language studies will become more common in the US, and creative use of computing power will make those language studies more efficient and more effective. Going along with the rise of the global marketplace will be the global laboratory, and the United States will become less insular in the process.

Scholarly Communication

Next, let's consider the nature of scholarly communication. In the world of peer review, our established way of doing things is that research manuscripts are prepared at the completion of a project. These manuscripts are submitted to journals, whose editors send them out for review. When a paper is accepted, it then goes into the queue for publication in the journal, and eventually arrives to libraries and individual subscribers in the mail.

One change is that the number of electronic journals is growing prodigiously. As but one example, this year the American Chemical Society has made all its journals available online. And we are entering an era where researchers make their results instantly available on their home pages, and peer review thereby comes after that form of publication, rather than before. Instant publication on the home page can be critical in a fast-moving field. Furthermore, a publication on one's home page can be a living document, changing in response to comments from others and even building upon the new research results of others. One can picture a paper with references forward in time, as well as back in time. Or a paper with chapters written at different times. Or a system where authors continually revise as general knowledge becomes greater. In such an environment, archiving becomes a vaguer concept. Which form of a paper do you archive, and how and where?

Tensions have grown up between research institutions and publishers. These will increase, but the two will eventually reach an accommodation. Universities and research funding agencies have recognized that the research publications of their faculty members are given to publishers for free or even with page-charges to be paid. Then peer reviewing is done for the publishers by faculty for free, and the universities buy the resultant journals back at high library prices. The purchasing power of the library dollar is descending rapidly, reflecting several causes. One is price increases, due to the consolidation of the publishing industry and hence less competition within it. Another cause is the proliferation of journals, especially from private publishers. New sub-fields arise, and researchers in it focus their publications into a new journal specific to that subfield. Pricing policies for electronic journals have yet not helped much. Publishers still want to make a buck, often many bucks.

There is a movement from the Association of American Universities and others to separate the peer-review process from the publication process, with the peer-review function taken over by professional societies or university associations. In the extreme, universities or groups of universities are considering going into the research publication business themselves. Publishers and media companies, on the other hand, want to make money or at least do not want revenues to decrease. They are properly concerned that electronic publication makes it difficult to protect publications against prolific reproduction without payment. At the heart of this matter is the debate over copyright laws and policies, and preservation of "fair use" in connection with electronic media. The outgrowth of this turmoil will hopefully be a realistic fair-use policy and quite probably joint ventures between publishers, media companies and and university associations or major universities themselves to meet the needs of both. Alternatively, the role of the university presses may expand.

And so, where will this all head? I think it will be to living, electronic publications, and to more interactive forums and public conversation among authors, and toward review after the fact of publication. The role of the printed page will shift toward the archiving of a sub-set of the best or most lasting publications.

The Information Base for Research

Where will researchers derive their information? The repository of research publications is the library, which will itself undergo radical changes. The University of California is not alone in investing major resources in a digital library project. In our case we are driven not only by the advantages of digitized information, but also by system-wide efficiency and, hopefully, economy. Ours is a single digital library for the nine-, soon to be ten-, campus system, and it is also working in close conjunction with the California State Library, which means the public library system.

To what form will the digital library evolve? It doesn't take much imagination to see large repositories of highly network-linked hypertext documents, enabling users to shift back and forth rapidly on the basis of these links and very efficient search engines. The fields utilized will include researchers' home pages and all sorts of multi-media and Internet materials. Yahoo and its relatives will be looked upon as a crude start, and browsing the shelves in the stacks will eventually become a thing of the past. The Dewey Decimal System, our stalwart for a century, fades in power by comparison.

The Structure of the Research Enterprise

Who will do research, and who will pay? For answers to these questions we should look at what sorts of institutions are best suited to do what, and at who derives the economic benefits of the research. We should then factor in the effects of change.

Industrial research obviously needs to serve the direct, bottom-line interests of the company. Criteria will be a good return to the investor in the research, and a return to the investor

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that is a large fraction of the total return to society. Thus industrial research will be applied R&D building upon promising leads from fundamental research. It will also be targeted, and proprietary, exploratory research. No surprises there.

Research universities, on the other hand, are well suited for research that leads to new knowledge, insights and discoveries. Universities also have the prime role in the interpretation and generalization of knowledge. As has been the case, the societal rate of return will considerably exceed the return accruing to the actual investor in the research. Therefore it is appropriate that the bulk of funding for university research continue to be public, and that means federal dollars. Where there is a perceived benefit to a state, the funding can come from the state government. The work on rates of return that I cited earlier provides a cogent rationale for federal investment in research. Indeed that work and work that will follow it will show that using federal dollars wisely for research is one of the best investments that a country can be make for economic expansion. However, this growing recognition will continue to feed the paradigm that research should be judged on the basis of likely worth to society. We will do research for society's sake, not research for research's sake. With this caveat, I believe that university research will continue to do well, even well enough so that universities can, as they should, invest more time and energy in explaining the value of that research to society.

With the wind-down in corporate research in many industries came a renewed interest in industrial sponsorship of university research, and the growth in that area has indeed been considerable. However, there are limitations on the ability of university research to serve industrial needs directly. These limits are more fundamental than the conflict-of interest issues that have lately concerned universities, government and the public. University research, given its nature and the goals of universities, should in most cases not proceed far enough down the route of commercial application for a company to be able to pick it up and use it directly. Instead companies, or in some cases associations of companies, need to carry out stages of technology-specific applied research and development before they can commercialize the fruits of academic research productively. This fact has led and will continue to lead to a revival of corporate research in many of those industries that had cut back considerably. However, it will be a different sort of research, building to a greater extent and more directly on university research.

This leaves the perennial question of the roles of the national laboratories, particularly in the post-cold-war era. There are indeed missions to be addressed by national laboratories that cannot be fulfilled well in other ways. And they are vitally important missions. One is defense. But there is also much research directed toward other major national and international needs. Some good examples are global warming, methods of utilizing energy efficiently, building codes, environmental science and methods of environmental protection, and even aspects of criminology and criminal justice. A common feature of these missions will be that the societal or national rate of return considerably exceeds the rate of return to the investor in the research.

Research partnerships will grow considerably within and among different sectors of the research community, both in number and in complexity. Drivers for the growth of partnerships are the growing expense of major research facilities and the synergies to be obtained by combining the capabilities of institutions from different sectors. The example of telescopes is already here and has been for some time. There are already some research buildings shared between universities and companies, and between universities and government. There will be more. National laboratories have a role that will only increase for providing and maintaining large and expensive multi-user research facilities.

The Size of the Research Enterprise

In addition to the structure, there is the matter of the size of the research enterprise. This is an issue to which universities must be especially sensitive. For years we have had a situation where the number of PhDs graduated in the next academic generation far exceeds the number in the generation before. In my own case, I have had 46 PhD graduates, with three more on the way. Of the 46, eleven are in, or have had, academic careers. And many of the rest work in research, most in industry and some in government. So my generational multiplication factor has been eleven from the standpoint of university faculty alone, and substantially greater for the research enterprise in general. And I don't think I'm so unusual.

The extra output to the PhD job market has been taken up in the growth of the number and size of research universities, as well as by increased use of PhDs in some areas of industry. This situation cannot sustain itself. There is a need to pare down the rates of production of PhDs within the system of research universities.

Obvious ways to do this are to have fewer research universities, smaller departments within research universities, and/or fewer PhD students in research groups. Other, less obvious routes are narrowings of academic scope within individual universities, differentiation of emphases among universities, and a paradigm shift whereby professional researchers populate academic research groups to a much greater proportion than they do now. This last approach would decouple the size of the academic research enterprise from the rate of production of PhDs and post-docs, but it would lose much of the intimate synergy between academic research and education. Any of these avenues require coordinated institutional planning, or a sort that may not mesh well with the ambitions of institutions, state governments and governmental representatives. But there will be far-sighted institutions that will bite the bullet and do some or all of these things.

In the absence of national planning and design, for which there are not yet effective mechanisms, there will be a war of attrition among research universities, with the survivors being those that can compete best for funds, faculty and students. In this connection, any good Californian should point out the worth of the California Master Plan for Higher Education, which has set up three sectors of public higher education, only one of which has the research mission. The Master Plan is a valuable commodity, deserving of export to other states.

Education in Research Universities

Let's talk now about education itself. The forte of research universities is the synergy obtained between the research function and the teaching function. This interaction is most evident in the tutorial supervision of dissertation, thesis and undergraduate research by faculty. Through this mechanism, and through a general spirit of inquiry and the incorporation of research concepts into course material, the research university is uniquely equipped to bring out creativity in students, and thereby to be the key provider of the creative element to society.

A major objective for research universities has to be to make this role — the generation and nurturing of inquiry and creativity — better understood by the public.

The multi-dimensionality of the modern world places demands on scientists and engineers far beyond their education in science and engineering themselves. Education in these fields will broaden, particularly in engineering, to encompass aspects of social science, human culture and policy. Engineering education will move to become like medicine, where a general pre-engineering education is followed by the graduate professional degree. In the case of engineering the professional degree will become the Masters.

Research universities, particularly public ones, belong to the people and must serve the needs of the people to maintain support from the people. Research universities will therefore considerably increase their efforts to attract and prepare persons from all sectors of society so that those who will profit most from a research-university education can partake of it.

Methods of instruction will grow to take full advantage of multi-media methodology, networking, and distance learning. With more variety of this sort, we will finally emerge from the limitations of the conventional world of classrooms and courses. For the major research universities this will be more an improvement in quality, educational opportunity and flexibility than it is a way of gaining cost efficiency. It will be possible to obtain presentations in many forms from the best educators nationwide and worldwide. The four-year, coming-of-age experience for undergraduates has considerable value beyond the classroom component and will continue to be in strong demand. The instructor at hand will still be there, but will have a role that moves more toward that of interpreter, mentor, reinforcer and coach.

As well, research universities have an important place in continuing education and lifelong learning, particularly in the creative arts and sciences and in the professions. The role of research universities is distinctly different from that of institutions such as the University of Phoenix, in continuing education and bachelors-degree education, as well as research. Both sorts of institutions have their place. But once again, the California Master Plan is worthy of exportation.

Conclusion

What I have tried to do today is to outline the coming nature and roles of research universities. In addition to the grand opportunities presented by the information age, the other signal trend for universities will be the growth of partnerships of all sorts with industry and government, within and across international borders. In the world of Government, Academic and Industrial Interactions in the New Global Economic Environment, as denoted by the title of your special symposium, universities certainly have their place. And there are very exciting, challenging and profound changes in that role.

I appreciate your attention and wish you all well for a fruitful and productive annual meeting. ■