Issues Driving Reform of Faculty Reward Systems to Advance Professional Graduate Engineering Education: Differentiating Characteristics Between Scientific Research and Engineering

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Abstract

This is the second paper in the special panel session focusing on issues driving reform of faculty reward systems to advance professional graduate engineering education for creative engineering practice and to stimulate leadership of technology innovation to enhance U.S. competitiveness. This paper addresses the characteristics that differentiate the pursuits of basic academic scientific research and of professional engineering practice for the systematic creation, development, and leadership of new and improved technology for purposeful innovation in industry and government service.

1. Background and History

Whereas in the last half of the last century, faculty reward systems that assessed productive faculty scholarship at the nation's schools of engineering and technology have been based largely on the linear research-driven model of engineering innovation (originating in 1945 U.S. science policy)[1], a new model for needs-driven, systematic engineering innovation has emerged in the 21st century. Scientific research and professional engineering practice are no longer viewed as linear, sequential activities. Today, creative professional engineering practice and directed scientific research are viewed as concurrent activities with unique missions and functions.

1.1 Status of U.S. Engineering Graduate Education

Although the U.S. system of engineering graduate education has served our nation well for the further graduate education of academic scientific researchers at the nation's schools of engineering (and must continue to do so), the professional complement of engineering education must be reinforced substantially to meet new challenges of the 21st century relevant to the practice of engineering itself for the leadership of creative technology development and innovation in industry and government service.

Since the end of World War II, the United States has invested heavily in fostering research-driven graduate education for the further development of the U.S. scientific workforce who perform research at the universities. In hindsight, however, it is now apparent that a balanced investment has not been made in fostering a complementary path of professional graduate education for the further graduate development of the nation's engineers during this same time period contributing to a long-term underdevelopment of the U.S. engineering workforce and subsequently reflected in the loss of U.S. competitiveness for technology innovation.

1.2 Engineering Graduate Education, Creative Professional Practice, and Research

As the nation competes in the 21st century, we can no longer afford to consider engineering graduate education and research as one word. However, because of 1945 science policy (Vannevar Bush Report- *Science: The Endless Frontier*) and an avalanche of federal funding (holding the central theme that basic scientific research performed at the universities is the primary source of U.S. technology innovation for economic prosperity and for national defense),[2] U.S. engineering graduate education grew in the 1960's – 1990's largely as a by-product of academic research.[3]

With the Bush report, a covenant was established between federal government and the nation's research universities. Increased emphasis was placed on basic research for the advancement of science and on the simultaneous graduate education of academic researchers at the universities because they were perceived as the primary generators of U.S. technology. By this scheme, academic scientific researchers would be trained at the nation's universities and university research findings would be transferred as the principal *"wellspring"* for engineering development in industry as a secondary, follow-on activity for conversion of new scientific knowledge into new products, processes, systems, and operations. This scheme became known as the linear research model for technology innovation.

1.3 Long-Term Decline of US Innovative Capacity for Technology Competitiveness

Today, research has become the foundation for engineering graduate education at most schools of engineering across the nation. By every measure, America's investment in its 1945 science policy as the blueprint for strengthening our scientific enterprise through graduate education and research is paying valuable dividends for the advancement of science. But that does not mean that the system of U.S. engineering graduate education cannot be improved for the advancement of technology.

While the nation has gained preeminence in academic scientific research and research-oriented graduate education, it has lost ground in technology and professional engineering education. There has been a long-term decline of U.S. technology competitiveness and loss of America's innovative capacity for creative technology development in industry. Several factor have contributed to the loss of America's technology competitiveness, but if engineering graduate education has anything at all to do with the development of our creative intellectual capital, responsible for the engineering advancements of new technological developments and innovations, then the present health of U.S. engineering graduate education itself must be included as a major contributing factor in the loss of US competitiveness.

1.4 Technology Matters — The Changing Practice of Engineering for Systematic Technology Innovation

The assumption that federally funded basic scientific research (performed at the nation's research universities) is the principal generator of US technology for economic growth and national security has been fundamental to U.S. science policy since the end of World War II. But after three decades of federal funding and academic emphasis on singular use of the linear research model (as the sole source of US technology innovation and principal driver of engineering development in industry), there is a heightened sense of national urgency that the 1945 linear research-driven model of technology innovation is outmoded and only partially true.[4,5,6,7]

This finding does not mean that the pursuit of basic academic scientific research and the education of future academic researchers are not important. Both are vitally important to the nation's welfare. But so are the pursuit of creative engineering practice in industry and government service and the education of the nation's creative engineering talent for leadership of technology development vitally important to the nation's welfare.

The finding that the linear research-driven model of engineering innovation is outmoded does mean, however, that the creative intellectual capital for future U.S. technological advancements resides primarily within the U.S. engineering workforce in industry and government service; and that new, improved, and breakthrough technological advancements result primarily from a different method than that portrayed by 1945 science policy.

The U.S. Department of Defense recognized this finding as early as 1967 and subsequently based its preeminence for military advanced technology developments on a different model of technology innovation because it was too important to place the nation's defense on the linear model of 1945. The national implications of this finding and the necessary actions required in reshaping the future direction of professional engineering graduate education to enhance the vitality of the US engineering workforce for competitiveness in industry are profound. As Jewkes (emeritus professor at Oxford) pointed out: "The theory that technical innovation arises directly out of, and only out of, advance in pure science does not provide a full and faithful story of modern invention."[8]

Although basic academic scientific research performed at the universities continues to be the backbone for sustaining the nation's future advancement of scientific progress, it is now understood that *sole* use of the linear research model for technology innovation is no longer reliable in sustaining the nation's systematic engineering advancements for technological progress in industry for our economic growth or for our national security. As the 1988 Council on Competitiveness Report pointed out: the belief that technology innovation progresses primarily in a step-wise fashion and as a linear-sequential process from basic research to development is largely myth and does not represent reality.[9]

Both science and engineering are important in the modern process of technological innovation. But the activities of basic scientific research and creative engineering practice are no longer perceived as stepwise, linear, and sequential functions. Instead these activities are now viewed as interwoven and concurrent: each with a separate function and purpose. As the nation competes in the innovation-driven economy, the model of engineering innovation and the practice of engineering for creating, innovating, and leading the development of new useful technology have changed substantially from that portrayed by the simplistic model of 1945 science policy and reliance on a linear basic research-driven model of technological innovation.

Technology development is viewed today as a deliberate creative process of engineering that is driven by real-world needs which is supported by directed (applied) scientific research. The conventional model, portraying that the majority of technological developments arise from [Basic Research] → [Engineering] → [Technology] as a linear sequential process (resulting in new and improved products, processes, systems, and operations) is outmoded and is no longer effective for ensuring U.S. innovative competitiveness for economic prosperity or in ensuring advanced technological developments for our national security.

Policy Blind Spot: Disconnect Between
Engineering Graduate Education and Professional Engineering Practice

Although industry has voiced concern over the "competency gaps" of engineering graduates and the need for reform to better meet the graduate educational needs of the nation's engineers in industry, U.S. engineering graduate education continues to focus primary emphasis on preparing students for academic careers as research scientists without providing a complementary path of excellence of professional education for creative engineering practice and engineering leadership for engineers assuming responsible technology leadership roles in industry.

After four decades of an unbalanced emphasis on research at the nation's schools of engineering, many engineering faculty are expert for teaching research, but they are ill prepared and have little experience for teaching engineering practice at the graduate level. Yet, less than 5% of U.S. engineers are engaged in academic scientific research, which represents a major "disconnect" between U.S. engineering education and practice. Fred Gary, former corporate vice president of engineering at General Electric Company, pointed out several years ago that technology development is the primary function of engineers in industry.[10] Most engineers work on development and production-related tasks and in management. Less than 5 percent of engineers are engaged in research and less than 1 percent in basic research.[11]

2. Urgency for Engineering Graduate Education Reform To Stimulate US Technology Innovation for World-Class Competitiveness

Today we know that there are differences between science and technology; but the differences are not what most people think. Confusion between science and technology is pervasive at all levels of education—including higher education. This confusion reflects the "root cause" for much of the disconnect between U.S. engineering graduate education and the professional practice of engineering required for creating, innovating, and leading the development of new, improved, and breakthrough technology to ensure U.S. competitiveness.

2.1 Technological Literacy

Whereas the public's understanding of science (scientific literacy) and its importance to the nation have gained broad recognition, parallel efforts to foster the public's understanding of technology (technological literacy) have remained largely unaddressed in spite of its importance. As Bugliarello notes: "The fundamental difference between science and technology is ignored or not appreciated. It is the difference between understanding and modifying nature, between searching for the whys of nature and engineering the artifacts that respond to our needs and extend our capabilities."[12]

As Theodore von Karman noted years ago

> *Scientists study the world as it is,*
> *Engineers create the world that has never been.*

The commonly held viewpoint based on the misperception that scientists seek a systematic understanding of the physical world and engineers seek to apply that knowledge for the practical benefit of people is not adequate, and never was. In order to raise awareness among policymakers, the education community, and the public at large about the importance of technology, the National Academy of Engineering (NAE) has taken a major step to create the Committee on Technological Literacy. As the result of a two-year project initiated by William A. Wulf, president of the National Academy of Engineering, and chaired by A. Thomas Young, retired executive vice president of Lockheed Martin, the Committee on Technological Literacy has recently completed a landmark report *Technically Speaking: Why All Americans Need to Know More About Technology*.[13]

Although the Technological Literacy report is intended to improve the public's understanding of technology and to improve K-12 education, the National Collaborative Task Force on Engineering Graduate Education Reform believes that the report also serves to lay a conceptual foundation that is required to accelerate needed reform within the nation's schools of engineering and technology themselves. The report highlights fundamental aspects of technological literacy, which serve also as a driving force for reshaping engineering education. These fundamentals include the following:

- Science and technology are no longer considered as sequential, linear activities. Nor is one considered of higher importance than the other to the nation's welfare. Both are needed in the development of technology. But they are quite different activities with distinct purposes, methods, and processes requiring practitioners who pursue these two different activities to develop distinct skill-sets, knowledge, and experiences in order to compete effectively in the new innovation-driven economy.
- Technology is no longer regarded as an independent force or a separate thing flowing on its own. It is a purposeful activity of creative human pursuit under human direction. Technology involves both the purposeful processes of science and engineering. But, technology is no longer viewed merely as "applied science." Although many people believe that technology is the application of science to products and processes, it takes much more than applied science to create or improve technology in the form of new and improved products, processes, systems, and operations.
- Whereas the operant word for science is research, the operant word for technology is creative engineering practice. Today, technology is conceptualized, created, developed, and innovated primarily through a purposeful, deliberate systematic process, known as the "engineering method". As a purposeful process, engineering practice yields new technological change, economic-change, socio-change, and new technological knowledge as the outcome of deliberate needs-finding, purposeful conceptual design, development, innovative thought, hard work, and responsible engineering leadership. While science aims to understand the "why" and "how" of nature, engineering seeks to shape the natural world to meet human needs and wants.
- Engineering, therefore, could be called "design under constraint," with science — the laws of nature — being one of a number of limiting factors engineers must take into account. Other constraints include cost, reliability, safety, environmental impact, ease of use, available human and material resources, manufacturability, government regulations, laws, ethics, and even politics. In short, technology necessarily involves engineering and science.

2.2 What is Technology?

As the result of the Technological Literacy report, a new definition of technology has emerged for the 21st century. As the National Academy of Engineering (NAE) points out in its report: "In its broadest sense, technology is the process by which humans modify nature to meet their needs and wants. However, most people think of technology only in terms of its artifacts … but technology is more than its tangible products. An equally important aspect of technology is the knowledge and processes necessary to create and operate those products, such as engineering know-how and design, manufacturing expertise, various technical skills, and so on. Technology also includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts from corporate headquarters and engineering schools to manufacturing plants and maintenance facilities."[14]

2.3 What is Engineering?

The new definition of technology has cleared the way for specifying the differentiating characteristics that are needed in reshaping professional engineering graduate education to better meet the needs of the U.S. engineering workforce in industry. Clear distinctions can now be made between the aims of research-based graduate education for academic scientific research and those of professional graduate education for creative engineering practice and leadership of technology development in industry.

The characteristics that differentiate professional engineering graduate education from that of graduate education for academic scientific research can be distinguished best by using modern definitions of engineering as follows:

- "Engineering has a mission, purpose, and method … As a creative profession, engineering is concerned with the combining of human, material, and economic resources to meet the needs of society for the advancement and betterment of human welfare.

  As creative professionals, engineers purposefully conceptualize, design, and lead the systematic development of new innovative technology in the form of new and improved products, processes, systems, operations, and breakthrough developments which are responsive to real-world needs. In this process, they use the integrative engineering method as a purposeful, deliberate and systematic practice for innovation and entrepreneurship, driven by an engineering ethic and responsible professional leadership for improvement and betterment responsive to real-world needs.

  Whereas directed strategic scientific research is often necessary to gain a better understanding of phenomena during the systematic technology development process, scientific research is not the primary driver. Creative engineering practice requires proactive, responsible leadership beginning with the identification of meaningful real-world needs. During the purposeful, creative technology development process, engineer-leaders must anticipate the need for directed strategic scientific research and know when and how to integrate the scientific research activity, when necessary, for effective technology development."[15]

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- "Engineering is not science or even "applied science." Whereas science is analytic in that it strives to understand nature, or what *is*, engineering is synthetic in that it strives to *create*. Our own favorite description of what engineers do is "design under constraint." Engineering is creativity constrained by nature, by cost, by concerns of safety, environmental impact, ergonomics, reliability, manufacturability, maintainability … To be sure our understanding of nature is one of the constraints we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one."[16]

  William A. Wulf, president
  National Academy of Engineering

  George M.C. Fisher, chairman
  National Academy of Engineering
  Retired chairman, CEO Eastman Kodak

2.4 What Do Engineers Do?

As Fred Gary pointed out: "Development is the primary task of engineers" … and … "Great engineering is measured by the proper gauging of people's needs and the delivery of affordable, high-grade products and services."[17] But the development of technology is quite different from the pursuit of scientific research. As Martino, formerly of the Air Force Office of Scientific Research, has pointed out: [18]

- "The term "research" is defined here as an attempt to acquire new knowledge about some phenomenon in the universe, or about some phenomenon in an abstract model of a portion of the universe, which is not necessarily made with an application in mind. The definition makes no distinction between basic and applied research, since the difference between the two terms is usually in the motivation of the researcher."

- "There is, however, a meaningful distinction between research and development: development is an attempt to construct, assemble, or prepare for the first time, a device, material, technique, or procedure, meeting a prescribe set of specifications or desired characteristics and intended to solve a specific problem. This definition includes not only mechanical devices and hardware, but such things as computer programs, chemicals, and other materials."

- "The essence of this definition is that development is intended to meet some set of specifications in order to solve a specific problem … Research and development are two entirely different categories of activity, and there is no neat linear progression from one into the other … The kindest thing one can say for the (linear-sequential) model is that it is erroneous."

2.5 Engineering Method

The modern practice of engineering has changed substantially in the 21st century from that portrayed by 1945-science policy and singular reliance on basic research as the nation's primary driver for technological innovation. World-class engineering is no longer perceived simplistically as a linear sequential follow-on conversion process to scientific research — i.e., the conversion of scientific knowledge to practical use or the translation of scientific research findings into new technology — and it never was that. As Richard Teare pointed out at Carnegie Institute of Technology in 1948: "Problem solving is the main task of the engineer."[19]

As such, creative problem solving includes conceptual design, invention, development, and responsible professional leadership; beginning with the stage of needs-finding — followed by purposeful conceptual creation, design, development, and innovation of new technology to meet real-world human needs to advance the quality of life. Modern engineering includes a professional spectrum of creative activities from the stages of needs-driven exploratory development through advanced systems development and leadership of new/improved/breakthrough technology developments in the form of new products, processes, systems, and operations.

The sequential, linear basic research-driven model of technology innovation (See Appendix C) has now proven to be outmoded and out-of-date for the modern practice of engineering. As America competes in the new economy, professional engineering practice has evolved as a systematic creative practice for purposeful innovation. An integrative process, known as the "*engineering method*" for the deliberate and systematic creation, development, and innovation of new useful technology for competitiveness and national security, has emerged for the 21st century (See Appendix D).

In the 21st century, the lion's share of new creative technology developments results primarily from direct application of the "engineering method" for needs-driven technological innovation that is performed primarily in industry and mission-oriented technology-based government agencies. Today, engineering development in industry frequently drives directed scientific research investigations at the nation's research universities and not the reverse. Donald E. Marlowe, a former president of the American Society of Mechanical Engineers noted: "Engineering is the primary source of technological innovation and economic growth."[20] The power of the new integrative model for "systematic engineering innovation" has profound impact upon the nation's continued technological progress for competitiveness, economic growth, national security, and our defense.

2.6 Broad Interpretation of Engineering Practice: From Need to Conceptual Design, Development and Innovation of New Technology

As part of its tasks, the National Collaborative Task Force for Engineering Graduate Education Reform is addressing the meaning of "engineering practice" itself. Traditionally, engineering education has regarded engineering practice as simply the application of knowledge gained at the university to problems in industry. But creative engineering practice in industry or government service is much more than that.

The conventional academic model portraying Scientific Research → New Knowledge → Teaching → Learning → Application of Knowledge (Practice) is too narrow, limiting, and outmoded at the graduate professional level of engineering practice for leadership of technological innovation in industry.

This model leaves out the professional dimensions of engineering, self-directed learning, need-finding, problem-definition, program-making and the development of engineering creativity, innovative capacity, leadership, integrity, and responsible judgment (encountered in creative engineering practice) which are required in the creative solution of unsolved real-world problems and to meet needs that have never been met before or improved upon. Today, creative engineering practice operates at the margin of meaningful solvable problems and at the cutting edge of technology.

3. Deficiency in US Engineering Graduate Education
For Creative Engineering Practice and Leadership of Technology Development in Industry

As Wulf has observed, the practice of engineering is fundamentally a very creative process. "Engineering is not applied science. Whereas science is analytic to determine what is … engineering is a very creative profession to create what has never been." The problems and real-world needs encountered in creative engineering practice are not routine. As such, engineering purposefully expands the state-of-the-art of useful technology through creative conceptual design, invention, development, and responsible leadership of technology to meet real world needs. The National Collaborative Task Force for Engineering Graduate Education Reform has chosen a broader definition of engineering practice than the traditional graduate educational model allows.

We believe that engineering practice includes a broad spectrum of creative professional activities from conceptual design and creative engineering development — including the functions of exploratory engineering development, advanced engineering development, advanced systems and operations development — to the highest levels of engineering leadership which include needs-finding, program-making, and technology policy-making for product developments, manufacturing developments, large-scale multidisciplinary systems development, and technical operations.

To date, however, the U.S. system of engineering graduate education has not reflected:

- The distinctions between science and technology at the graduate professional level.
- The context of creative engineering practice and the systematic engineering method for purposeful, needs-driven technological innovation that has evolved in technology-based industry and government operations.
- The educational differences that must occur at the professional graduate level between a scientific education for research and that of a technological education for creative engineering practice and leadership of technology innovation in industry.
- The types of faculty, organizational differences, contextual differences, cultural differences, and faculty reward systems that are required to initiate and sustain high-quality professional education in engineering at the graduate level as distinct from research-oriented graduate education.

Although notable changes have already been made in engineering graduate education they have been piecemeal at best, and have not been integrated as a whole across the nation or reflected in mainstream operations at most schools of engineering and technology. Many schools of engineering and technology continue to emulate scientific education for academic research. Because of an unbalanced emphasis on academic research, as the sole source of technological innovation, too many schools of engineering and their faculty have lost sight of engineering as a purposeful, creative profession concerned primarily with creative problem-solving, conceptual design and development, and responsible engineering leadership of technological innovation to meet real-world human needs to advance the quality of life, the nation's economic growth, and national security.

As a result of this unbalanced emphasis at the nation's engineering schools, a major educational deficiency exists in the U.S. system of engineering graduate education at the professional level for the further professional graduate education of the US engineering workforce in industry — which is the nation's primary intellectual capital for the creation, advanced development, and innovation of new competitive technology for the nation's economic prosperity, national security, and defense.

3.1 Seriousness of the Deficiency in Professional Graduate Engineering Education and U.S. Technological Competitiveness

Although the United States has achieved preeminence in research-driven graduate education and has developed a strong U.S. scientific workforce at the nation's research universities and government laboratories, it has neglected the fullest professional graduate education of a strong U.S. engineering workforce in industry during the last three decades. The long-term effects of the deficiency in engineering graduate education have contributed to the long-term underdevelopment of the U.S. engineering workforce and to the long-term decline of US innovative capacity for technology development. The results of the long-term underdevelopment of the US engineering workforce have shown up by loss of America's competitive edge and by a long-term decline of the nation's capacity for creative technology development in too many industries.

Recognition of the seriousness of the insufficiency of engineering graduate education to meet the needs of the U.S. engineering workforce has been slow to emerge in academia being masked by 1945 science policy and the quest at universities for federal funding for academic research. The disconnect between engineering graduate education and engineering practice has occurred largely because of flawed belief originating in 1945-science policy that the majority of engineering developments in industry flow primarily from basic research generated at the universities. Some does …

But, the primary source, creative intellectual capital, and *"wellspring"* of US industry's capacity for innovative engineering development of new, improved, and breakthrough technological innovations resides largely with the creative, innovative, and leadership effort of the US engineering workforce that industry employs. Rebuilding America's innovative capacity for technology development is heavily dependent in turn upon the educational capacity of America's universities to provide advanced professional engineering education at the graduate level that supports the further development of our unique engineering talent in industry. As pointed out in the National Research Council Report, *Engineering Employment Characteristics*: "Advanced engineering programs involving innovative products and processes must find leaders among those who conceive or understand the development that is the impetus for the work."[21]

3.2 Urgency of Engineering Graduate Education Reform

Whereas Wulf, and others, have correctly called for urgency of reform of undergraduate engineering education to better prepare young engineering students for entry into engineering practice,[22] urgency of reform exists within graduate engineering education as well. But reform is not to change traditional research-based graduate education, which is "excellent" for its intended purpose to prepare future academic researchers in the context of inquiry-based learning. The need for graduate reform is to build a new type of post-baccalaureate professional graduate education that better supports the career-long growth of the nation's engineers — after entry into engineering practice — relevant to the responsibilities, skill-sets, and professional dimensions of advanced engineering practice and which fosters engineering leadership of creative technology development and innovation in industry for US economic competitiveness.

4. The Competitiveness Process For Innovative Technology Development Takes Place in Industry

Universities play an important role in supporting U.S. competitiveness through scientific discovery. But their role has been underutilized in supporting U.S. competitiveness through professional education of the nation's engineers. To date, primary attention has been given to the connections between basic research in universities and economic competitiveness. But as Ralph Gomory, president of the Alfred P. Sloan Foundation and a former senior vice president for science and technology at IBM, and Harold Shapiro, president emeritus of Princeton University, have pointed out: "A lot has been said about the connections between basic research in universities and economic competitiveness, but that relationship is often extremely remote. The competitiveness process takes place in industry, at the level of the individual company."[23]

As Gomory and Shapiro point out, engineers in development and manufacturing operations in industry largely run the race for competitiveness. Because these engineers operate at the frontline of improving U.S. competitiveness, both on a daily basis and on a long-term basis, the National Collaborative Task Force for Engineering Graduate Education Reform believes that improving the connections of professional education to the growth needs of engineers in development and manufacturing operations in industry will build a formidable strategy for immediate and long-term improvement of U.S. economic competitiveness.

As Whitfield has pointed out: "It is taken as self-evident that the creative output of engineering will be raised quickest and over the widest area by successful efforts to improve the creativity of the engineers already in industry — specifically the engineer who has added an adequacy of experience to his basic technical training."[24] We believe that Whitfield's proposition is correct if we develop a new concept for lifelong learning at the professional graduate level of engineering education to further develop the innovative and leadership potential of our working creative talent in the U.S. engineering workforce and if we improve also U.S. undergraduate engineering education to serve as the initial pipeline of U.S. creative engineering talent for entry into engineering practice in industry.

4.1 Purposeful Technology Innovation — Not By Science Alone: Why Needs Pull Engineering Beats Technical Push

The National Collaborative Task Force believes that improving the nation's capacity for professional engineering education at the nation's schools of engineering and technology is of critical importance to enhancing the vitality of the nation's innovative capacity of technological development for economic growth and national security. Educational efforts to grow the nation's engineers in industry as creative professionals and leaders of technology should play an equal or perhaps even greater role in the enhancement of U.S. competitiveness and national security, as does basic research. As Wulf and Fisher have pointed out, engineering is not science or even applied science … Engineering is "design" under constraint. And one of the constraints is our understanding of nature (basic science).[25] But the constraint is not the driving force for the advancement of technology to meet real-world needs of people.

Although being first in basic scientific research is extremely important to U.S. industrial strength, this does not mean that we will be first in technology. Technology and science are two different pursuits. A paradigm shift has occurred in the U.S. innovation system in the 21st century. Modern engineering practice is driven primarily by real-world, market-driven needs rather than by technical push from basic research laboratories as portrayed by 1945 science policy. While outsourcing is a current trend, U.S. technology-based companies must rebuild their in-house engineering capability for leadership of needs-driven creative technological development/innovation if they are to remain competitive. As John A. Armstrong, former vice president for science and technology at IBM, has pointed out:[26]

- "The end of the Cold War and the increased international competition among national economies is forcing a shift in U.S. priorities, and with it a reevaluation of the rationale for federal support of university research. In considering this shift, we should keep in mind that the lion's share of the responsibility for deficiencies in our industrial performance rests with the failures in the private sector, failures of strategy, investment, training — failures, in short, of management."

- "These will not be cured, or even helped, by more research. Trying to cure poor industrial performance with more university research is like getting helpers while pushing on a rope. Although it is an issue, and deserves attention, poor technology transfer from the university or national labs to industry has not been a major cause of our competitiveness problem."

- "There is some danger, therefore, that society at large as well as faculty and administrators will overstate what universities can contribute (because they are trying to maximize support) … and tend to overestimate the importance of science in technological competitiveness."

4.2 Engineering Leadership of Continuous, Systematic Technology Innovation

As Armstrong and Gary have voiced,[27,28] at IBM and General Electric Company, respectively, basic research plays an extremely important role but it is a small part of the industrial RDT&E investment. The same is true for the nation's defense investment. Both science and engineering (S&E) are needed — but the percentage of investment for each is different because each serves a different purpose and function in the development of technology. Over 90% of the nation's investment in military systems focuses primarily on the conceptualization, development, testing, refinement, and innovation of "ideas" and "concepts" generated through deliberate systematic engineering efforts in RDT&E (See Appendix E).

Many of these technological efforts are at the engineering forefront of technology even though the engineering practitioners who create these developments may be unduly modest. As Akio Morita, former chairman of Sony Corporation, pointed out: "Knowing how to make the best use of your engineers will be the test of whether a company will succeed in the coming age."[29] Today, engineering leadership is the driving force for technological competitiveness. Companies nationwide are recognizing that not only is the conceptualization and development of new/breakthrough products, processes, and systems important to U.S. competitiveness, but also is continuous incremental improvement of products, processes, systems, and operations extremely important.

But creative engineers don't simply walk around and collect new "ideas" and "concepts" from others or from the basic scientific research laboratory — although often useful. As creative professionals, these engineers purposefully conceptualize, invent and lead the development of new, improved, and breakthrough "ideas" and "concepts" — individually and in collaborative-multidisciplinary teams — in a systematic manner. During this creative process, experienced engineers use the engineering method, the principles of engineering practice, and the integrated whole of their skill-sets, knowledge, experience, and judgment as a primary part of their professional functions within modern innovative organizational cultures.

4.3 The New Paradigm of Systematic Technology Development: Integrative Engineering Method and Directed Scientific Research

As Sanders and Brown have pointed out: "Industry and government have developed a new concept of planned and systematized innovation, founded on vastly expanded scientific and engineering efforts. These institutions are now making regular provision for the occurrence of new and unpredictable developments."[30] A new paradigm for technological innovation has emerged — which is needs-driven, creative, purposeful, deliberate, and systematic. Engineering and scientific research are no longer perceived as sequential-linear activities in the technological process, but rather as concurrent and parallel activities. Each has a distinct purpose, function, and method. As Schmookler has observed: "Antecedent scientific discoveries are sometimes necessary, but seldom sufficient, conditions for invention."[31]

A good deal of technological knowledge arising from purposeful, systematic engineering development is fundamentally different from scientific knowledge arising from scientific research.[26] Whereas fundamental scientific research investigations, aimed at gaining a better understanding of natural phenomena, are extremely useful at certain stages of technology development programs, effective technology development programs do not start, for the most part, with new scientific knowledge as the driving force. There are other drivers of systematic, engineering development that accelerate technological innovation. These drivers include real-world needs for economic growth; threats to national security; needs for improvement in the quality of life; and the overall hopes, wants, and needs of people for a better future.

The essence of creative engineering practice is needs-finding, program-making, conceptual design, purposeful invention, development, and responsible leadership with judgment to meet these needs. The ultimate driving force for US technological progress then is the innovative capacity and creative effort (including the vision, imagination, ingenuity, values, resolve, professional competence, and leadership capacity) of the US engineering workforce in industry. These engineer-leaders must be educated with the technical competence, creative, innovative, ethical, and leadership capabilities and skill-sets to respond in a proactive sense to the real-world needs of our people for our economic competitiveness and our national security.

4.4 Crisis in the U.S. Engineering Workforce: We Must Renew Our Engineering Talent in Industry for Competitiveness

Today, the U.S. engineering workforce plays a vital role not only in creating and developing new technology but also by effectively leading the organizational process for technological competitiveness in the innovation-driven economy. Companies, nationwide, are realizing that the innovative capacity of the US engineering workforce is the nation's competitive advantage. However, the enormous creative, innovative and leadership potential of the U.S. engineering workforce for technological competitiveness has not been fully actualized because of the limits that US engineering education has imposed upon itself by restricting "bifurcation" and the fullest development of dual complementary paths of research-based graduate education for academic scientific research and of innovation-based professional education for engineering practice and technology leadership in industry.

This artificial constraint has occurred largely as the result of belief in the flawed 1945-science policy presuming that academic research is the primary driver of U.S. innovative engineering practice and sole source of technological advancements in industry. It is not. The nation has paid the price during the last thirty years as a result of this narrow vision and accumulated neglect of the professional dimensions of engineering practice by long-term underdevelopment of the U.S. engineering workforce and by the loss of U.S. technological competitiveness. A balanced educational focus is needed today to correct this error and to further develop the nation's graduate engineers in industry.

There is no doubt that graduate education for world-class academic research and professional graduate education for world-class engineering are both vital to the U.S. Science and Technology (S&T) innovation system. But the pursuits of science and engineering play two very different, unique roles for the nation's competitive advantage. Yet, to date, academia has not fully initiated, developed, and sustained appropriate models of professional graduate engineering education specifically designed to fully develop the nation's graduate engineers as creative professionals and leaders of technology throughout the working professional's career in engineering practice.

Today the nation is losing its long-term technological competitiveness with industrial cut backs, loss of engineering jobs, underdevelopment of the engineering workforce, and loss of a substantial part of the nation's experienced engineering leadership base due to retirements. Estimates indicate that 10% to 20% of our engineering workforce in our civilian industry and defense arenas will retire in the next five years causing loss of our experienced "creative intellectual capital" in engineering who are performing responsible leadership roles for continuous development and innovation of new technology to sustain our competitiveness, economic growth, and our national security. The seriousness of the existing deficiency in US professional graduate engineering education grows in importance as economic competition from other nations increases and as the United States faces a manning crisis in engineering.

5. Drawing the Right Conclusions

This paper has identified the characteristics that differentiate the functions of creative professional engineering practice for the advancement of technology from those of basic academic scientific research for the advancement of science. These differentiating characteristics make clear the need to establish a complementary framework of new unit criteria and faculty reward system based on clinical skill-sets and professional dimensions needed in creative professional scholarly work for professionally oriented faculty. Whereas unit criteria that emphasize research (discovery), scholarship, teaching, and engagement are already in place at most schools of engineering and technology across the nation, new unit criteria must be established that emphasize creative professional engineering practice (innovation), scholarship, teaching, and engagement if we are to make sustainable reform for the advancement of professional engineering graduate education across the nation. Unit criteria for academic research and for creative technology development are different. Without the establishment of such unit criteria for professionally oriented faculty in the nations' schools of engineering and technology, it is unrealistic to think that this needed reform in professional engineering education will be made.

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Appendix A

Functions of Creative Engineering Practice and Scientific Research

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Creative Engineering Practice

Creative Technology Development

… The role of needs-driven systematic technological development in industry and government is the purposeful invention and innovation of new or improved concepts, techniques, materials, devices, products, or systems and manufacturing processes. Its aim is to meet the hopes, wants, and needs of society, through change towards its general betterment, brought about by engineering development. It is creative and non-repetitive work and ranges from exploratory development, with concept and invention, through the experimental phases of feasibility to the advanced development and design of production prototypes and introduction into manufacture or operations. The primary base of needs-driven technological development is the conceptual ideas of men and women to bring about needed change for the benefit of mankind and improvement in the quality of life.

"Technology does not exist to serve itself. It is there to work for people – to improve the way they live, to safeguard their health, to preserve their environment(GE)" By technology, we refer to any "systematic, organized body of applicable interrelated concepts and ideas that is rational and valid enough to stand up under the test of experimental demonstration and experimental validation, and represents a common experience regardless of the society or nation in which it is observed (Alstadt)."

Scientific Research

Basic and Directed (Applied) Research

… The role of basic scientific research in industry and government is the pursuit of new scientific knowledge within specific fields of interest, which could be of potential use to the future business of the organization. Its aim is to discover, to describe, and to gain a better understanding of phenomena through creative in-depth investigation at the frontiers of a scientific discipline. The results will extend the existing body of scientific knowledge useful to the organization in the future.

… The role of directed (applied) scientific research in industry and government is the pursuit of new scientific knowledge in specific areas in direct support of development projects within the organization. Its primary aim is to discover, to describe, and to gain a better understanding of physical phenomena useful to the solution of specific problems anticipated or uncovered during the course of a technology development project. The results of this in-depth investigation and analysis will extend the existing body of scientific knowledge with committed use for the organization.

A secondary purpose is to provide technical consultation to other divisions of the organization whenever the existing body of specialized knowledge within the (applied) research group is needed for immediate problems.

Appendix B

Vannevar Bush, 1945 - Linear Research-Driven
Model of Engineering Practice

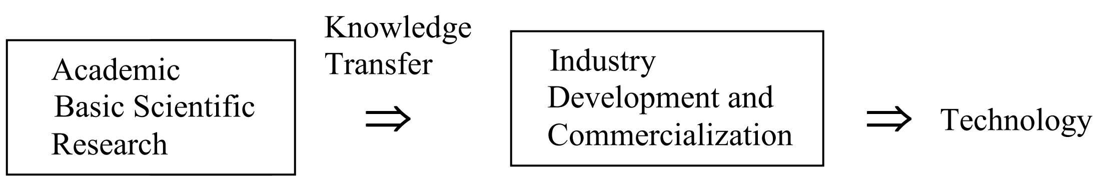
University Basic Research ⇒ Engineering ⇒ Technology

Basic Research ⇒ Knowledge ⇒ Teaching ⇒ Learning ⇒ Application (Service)

Appendix C

Vannevar Bush, 1945 – Linear Research-Driven Model of Technology Transfer

1945 - Technical Push Model of Engineering Innovation



Appendix D

Integrative Engineering Method for Needs-Driven Systematic Technology Innovation

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Needs Pull Model of Market-Driven Engineering Innovation

Needs-Driven Creative Engineering Development $\Rightarrow$ Useful Technology

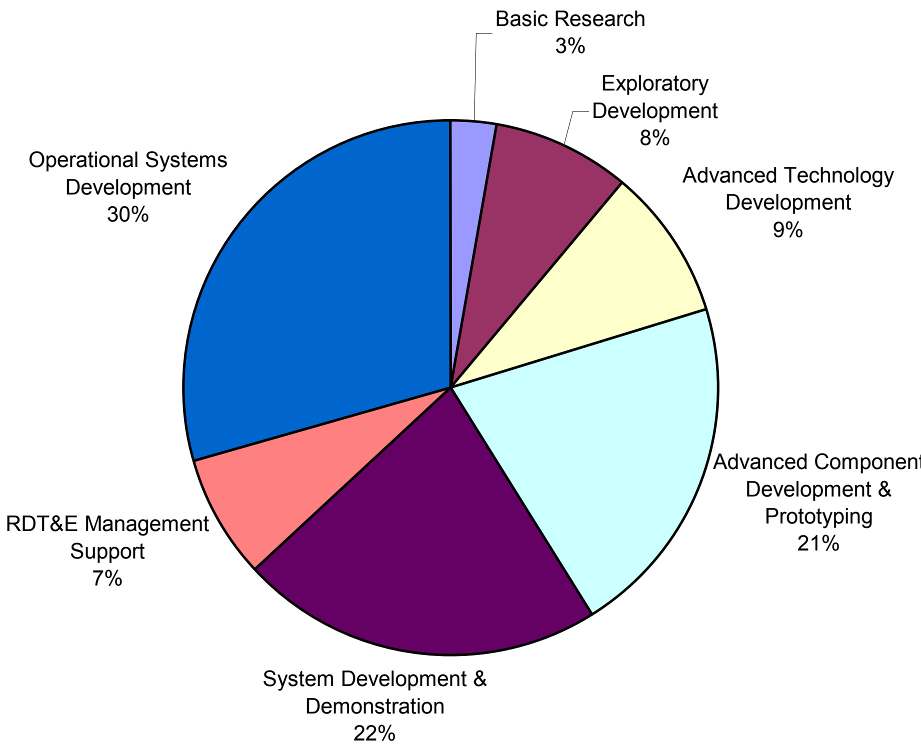
Ethic for Continuous Creative Engineering Development	$\Rightarrow$	Recognize Need(s) for Improvement	$\Rightarrow$	"Ideas" Concept	$\Rightarrow$	Proof of Feasibility	$\Rightarrow$	Advanced Development	$\Rightarrow$	Testing Modification Testing	$\Rightarrow$	Useful Technology

$\Downarrow \Uparrow$

Directed Scientific Research
Conducted to gain a better understanding
of phenomena either expected or arising
in the technology development process.
—Technology- Driven Science—

Appendix E

Comparative Investment in RDT&E Science and Engineering Activities for US Defense - DOD RDT&E Budget- FY 2002



Source: www.dod.cil/comptroller/defbudget/fy2004/index.html