An Innovative Strategy to Integrate Relevant Graduate Professional Education for Engineers in Industry with Continual Technological Innovation

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1. INTRODUCTION

As we approach the 21st century, the leadership of technology development and the graduate professional education of the nation's engineers in industry who create technology will become increasingly critical components of the U.S. effort to maintain competitiveness in the global marketplace. Continual technological innovation in industry is recognized worldwide as the principal driving force for competitiveness and economic prosperity. Without diminishing the importance of scientific research, it is now evident that continual technological innovation is primarily a needs-driven creative professional practice requiring engineering leadership.

Following a review of graduate engineering education and needs assessment studies of graduate engineers in industry, it is now clear that a transformation in graduate education is needed to improve U.S. technology innovation and competitiveness in the worldwide economy. As a national priority, the educational investment in the advanced professional education of industry's in-place graduate engineers, as primary leaders and innovators of technology, is a missing key that will impact the economic growth of our nation. While graduate education in the "context of research" has served the nation well in the training of future academics for research, there is a national need to reshape the graduate professional education of engineers who are pursuing non-research oriented professional careers in industry. This paper presents the conceptual basis for a collaborative university-industry strategy to reshape the graduate professional education of the nation's engineers in industry in a manner commensurate with their career-long growth for professional leadership of the continual technological innovation process in industry.

2. THE RESEARCH-DRIVEN MODEL AND THE TECHNOLOGY DEVELOPMENT MODEL

At present, graduate education of the nation's engineers is primarily a by-product of research, based on science policy and on a research-driven model of technology, largely set in place in 1945 by the Bush report, "Science: The Endless Frontier."[1] The Bush report was a landmark which outlined a program to the President for continual technological progress after the Second World War. It set the stage for national investment in postwar scientific research and in graduate education for future academic researchers which led to America's rise in scientific research and in graduate education at the research universities.

2.1 The Research-Driven Model

The Bush report built heavily on four main themes. The first of these is that technology is science-driven and flows from basic research which is the foundation upon which all technical progress is ultimately built. The report stated, "Progress depends upon a flow of new scientific knowledge. New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature and the application of that knowledge to practical purposes. Similarly, our defense against aggression demands new knowledge so that we can develop new improved weapons. This essential new knowledge can be obtained only through basic scientific research… Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn… Basic research is the pacemaker of technological progress." The second theme was that "… the responsibility for the creation of new scientific knowledge — and for most of its application — rests on the small body of men and women who understand the fundamental laws of nature and are skilled in the techniques of scientific research … the number of trained scientists available … So in the last analysis, the future of science will be determined by our basic educational policy." The third theme of the report was that to ensure technological progress the federal government is obligated to ensure basic scientific progress and should invest in the graduate research-oriented education of its future scientists. And the fourth theme was that the most effective way to advance science and technology was to award research funds to the most capable universities in the nation, which were therefore the "generators" of the nation's future technology and its future scientists.

2.2 Science Policy and Graduate Education for Research

Accordingly, graduate research education, funding, research faculty, and curricula to enrich the graduate scientific research path were largely built into the nation's engineering schools in the 1960's, 70's, and 80's. Consequently, American engineering education has primarily followed the research-driven model at the graduate level at the nation's research universities. The research universities have performed an outstanding job in meeting the science education and research goal. Those graduate engineers who are pursuing research careers have been especially well served. The nation is preeminent in scientific research and this educational model has worked well for research.

The effects of the Bush report have pervaded higher education worldwide, specifically in the ranking and funding of research universities and in programs of graduate research-oriented education, wherein technology is defined by conventional educational thinking as "applied science", based on Bush's linear model of research-driven technology. In the same context, the National Science Foundation (which Bush founded) has for several years defined the term "development" as technical activities of a non-routine nature concerned with translating research findings or other scientific knowledge into products or processes. In essence, the conventional university research and education model for the professions has evolved as:

curiosity → basic research → knowledge → teaching → learning → application in practice.

2.3 Needs-Driven Engineering Model of Innovation and Creative Technology Development

However, the Bush report, with all of its evidence and rightful justification for national investment in basic scientific research, was only partially correct. It misled, as Ferguson has pointed out, because it completely ignored the multitude of effective technology generated by graduate engineers in industry and government service, which was brought forth through the needs-driven creative engineering method and responsible leadership of innovation and technology development.[2]

Although the Bush plan has proven to be correct for excellence in scientific research and research-oriented graduate education at research universities to promote scientific progress, it is fundamentally in error for needs-driven creative engineering development of the nation's future technology and for professional-oriented graduate education of the nation's graduate engineers in industry to promote technology progress. Based upon the findings of the U.S. Department of Defense study, "Project Hindsight," innovative technology development is primarily a deliberate and systematic needs-driven creative practice of engineering — and it always has been.[3] The purpose of the investigation was to determine the contributions of the science-driven approach and of the needs-driven creative engineering development approach to America's acquisition of military technological systems capability since 1945. The study indicated that of the key contributions to military systems technology since 1945,

- basic scientific research contributed 0.3%;
- applied research contributed 7.7%; and
- needs-driven creative engineering development contributed 92%.

The lessons learned from Project Hindsight apply directly to improvement of civilian oriented technology policy and to improvement of educational policy to enhance U.S. technology competitiveness in the global economy. The lessons learned are threefold. First, that technology progress in war or peace is accelerated by real needs and a flow of new ideas to create solutions to real-world needs, or opportunities. Second, that there are two primary approaches to the acquisition of new or improved technological capability: the research-driven approach and the needs-driven creative engineering approach. Of the two primary approaches, the lion's share is generated by deliberate and systematic needs-driven creative engineering development from exploratory development — and proof of feasibility and concept — through advanced engineering systems development for operational quality, capability, cost-effectiveness, safety, environmental protection and customer use. Third, that the primary source and "generators" of the nation's future acquisition of technological capability for economic growth, for improvement in the quality of life, and for ensuring national security are the nation's creative graduate engineers in industry and government service.

2.4 Engineering Model for Needs-Driven Continuous Technology Innovation

Consequently, it is now recognized worldwide that the pursuits of scientific research and needs-driven innovative technological development are two distinct activities and processes; with discrete missions.[4] In essence the model for engineering leadership of systematic needs-driven continuous technological innovation has evolved as:

Continuous Creative Engineering Development	→	Recognize Need(s) for Improvement	→	"Ideas" Concept	→	Proof of Feasibility	→	Advanced Development	→	Testing Modification Testing	→	Technology

↕ ↕

Applied Scientific Research

Conducted to better understand
the physical phenomena involved
in technology development
Technology- Driven Science

3. ENGINEERING LEADERSHIP OF TECHNOLOGY DEVELOPMENT IN INDUSTRY

Based upon this new understanding of the needs-driven creative technology development process, it is now recognized that the engineering leadership of needs-driven technology innovation and industrial development is a unique multidimensional professional practice of increasing responsibility. As Martino points out, contrary to popular belief there is no neat linear progression from scientific research into technology development as the traditional model implies.[4] Scientific research and creative technology development are two different pursuits and the purposes, methods and talents of the people who engage in these endeavors are normally very different. Correspondingly, the myth that technology continually evolves primarily from scientific research, or somehow occurs in the world for managers to recognize and then exploit for economic gain, is now seen to be fundamentally in error.

3.1 Role of Creative Engineer-Leaders in Industry: Champions of Change

Engineering leadership of needs-driven technological innovation, creative invention, and the development of technology in industry is a deliberate and systematic process requiring engineering wisdom and value judgement to find, identify, or anticipate meaningful hopes, wants, and needs of people and industry, and to lead the innovative process to create a better future. It includes the use of known characteristics of "innovation best practice" and the characteristics of organizational "learning culture" wherein industrial creativity and innovation can flourish to create effective solutions to meet real-world human needs. It is now understood that innovative and competitive companies in the global economy focus on four primary core issues. They include: [5]

- Developing visionary, enthusiastic champions of change (engineer-leaders) who can lead the continuous technological innovation change process,
- Creating a learning and innovative organizational culture to unlock the potential of their people, in which people are seen as the key resource rather simply as a cost,
- Focusing on the needs of their customers to constantly learn and welcoming the challenge of demanding customer needs to drive innovation and competitiveness, and
- Constantly improving and creating new quality products, processes, systems, and services which constantly exceed their customers' expectations aiming to achieve competitive advantage.

3.2 Need for Creative Engineers as Innovators and Leaders of Technology in Industry

The educational development of graduate engineer-leaders who can lead the innovation process in industry is vital to continuous innovation and U.S. technology competitiveness in the global market. As Schumpeter stated, the question of innovation is one of leadership.[6] Accordingly, the United States will have either slow or rapid technological progress depending upon the number of highly qualified graduate engineers who are developing technology and leading the process of continual technological innovation in industry.

Most of the nation's graduate engineers enter industry or government service immediately after completion of their first formal degree education. A few remain at the universities to pursue research-oriented graduate work as graduate assistants in preparation for future teaching and academic research careers at research universities. As Garry, former vice president of corporate engineering and manufacturing at General Electric Company, has pointed out, "Development is the primary task of engineers … only 5 % of the engineers in the U.S. report their primary task as being research, and only about 1 % indicate that they do basic research." And, as Gary has noted, "… Great engineering is measured by the proper gauging of people's needs and the delivery of affordable, high-grade products and services."[7]

Therefore, it is now apparent that the primary ingredient for successful industrial innovation and improvement of U.S. technology competitiveness is the recruitment, retention, and human resource development of creative graduate engineers in industry who understand the technology of their organizations, and who are the "champions" and leaders of the continual technology innovation process in industry. As Morita, founder and former chairman of Sony Corporation points out, "… The challenge for all countries, not just ours, is management of new technologies, new development, and new products. We will need a lot of new ideas. Technology management will be the key to success for companies anywhere in the world in the coming years. Knowing how to make the best use of your engineers will be the test of whether a company will succeed in the coming age."[8]

4. RESHAPING GRADUATE EDUCATION FOR ENGINEERS IN INDUSTRY

Thus, a key factor in promoting U.S. technological competitiveness in the worldwide economy is the development and implementation of the opportunity for high-quality professional-oriented graduate education at the research universities to further nurture in-place graduate engineers in industry to grow to their fullest creative leadership potential. As Cranch has noted, most of the nation's graduate engineers in industry rise to positions of leadership responsibility within their organizations.[9]

4.1 The Creative Generation, Development, and Leadership of Technology in Industry

The need to continue the developmental growth of high-caliber graduate engineers in industry, as leaders and innovators of technology, is substantial and is national in scope. This need grows in importance as innovative competitiveness in the worldwide economy increases. This need is representative across the nation.

However, because of the lack of a coherent national policy and because of the lack of a program of support, the nation's creative resource base of graduate engineers in industry is the nation's underdeveloped creative human resource in the science and technology enterprise which limits the fullest capability for U.S. innovative technology competitiveness. It is now apparent that a correction needs to be made to improve graduate education for the majority of the nation's graduate engineers in industry who are pursuing non-research oriented careers for the leadership of continual technology development and needs-driven innovation. Since publication of the 1945 Bush report, the graduate education of the nation's engineers has evolved largely as a by-product of a national science policy based on the research-driven model of technology which supports research and the training of future academic researchers. Although the Bush report was correct in calling for a national program to support scientific research and for the training of future academic researchers at research universities, it was incorrect in its emphasis on a singular research-driven model of technology and in its neglect to call for professional-oriented graduate education for the nation's graduate engineers who primarily create and lead the technology process in industry. Because of the underlying belief in the singular linear research-driven model of technology, the nation's science and technology policies have been linked together as one policy.

4.2 Teaching Research Isn't Teaching Engineering

As a result there is neither a separate policy for technology nor is there a coherent policy for professional-oriented graduate education for the nation's graduate engineers in industry who are the primary creative generators and leaders of the nation's future technology. Both remain a by-product of science policy for research. In essence, the Bush research-driven model and resulting science policy was formulated on the strategy that the simplest and most effective way in which the Government can strengthen technology is to support research and to develop scientific talent. Consequently, the Bush report built heavily upon the belief that technology primarily flows in a linear research-driven manner from scientific research, which is generated at the nation's research universities, and which then flows or is transferred from the research universities to industry for application. Some does — but, the greatest portion of the nation's improved and new technology is generated in industry by the human resource base of creative graduate engineers in industry.

However, this is not to say that industry does not couple university scientific research efforts to industry's needs-driven technology development projects. Industry does. And it is cost-effective for industry to use the scientific research resources and faculty expertise that resides within research universities and to exploit the results of scientific research when applicable. However, as previously pointed out, needs-driven creative technology development and scientific research are two different pursuits. Subsequently, the creative generation and leadership of the nation's technology is inextricably linked to engineering creativity and to the further creative leadership development of the nation's graduate engineers in industry. The correlation is that if this creative human resource in industry is not further developed to its fullest potential, then most likely neither will continual technology improvements or breakthroughs in industrial innovations be developed and realized to their fullest potential over the long-term for economic development.

As Walker, former chairman of the National Science Foundation, pointed out in 1978, "Teaching research isn't teaching engineering. The key idea is that engineering is a system of management that results in the satisfaction of human needs… and, the effectiveness of an engineer is measured by how well he or she invents and innovates to meet these needs."[10] Correspondingly, the models of graduate education for scientific research and of professional-oriented graduate education for creative engineering practice and the leadership of continual innovative technological development are different. Each graduate educational model must be supportive of the activity and intellectual creative process for which it is intended. Yet, after three decades, graduate education at the engineering schools is still primarily tied to the singular linear research-driven model of technology development. There, the goals are viewed primarily as teaching undergraduates and, at the graduate level, as research for the discovery and dissemination of new scientific knowledge and the graduate education of future academic researchers. At present, the graduate education of engineers, with significant exceptions, has basically evolved as a by-product of educational policy for scientific research.

4.1 Time for Change

While general support for research-oriented graduate education programs has been underway in the United States for over three decades, it is now compelling and timely to build professional-oriented graduate education programs into the nation's graduate education and technological infrastructure. It is now recognized that graduate education must also serve better the needs of those graduate engineers whose careers are not centered on research, but rather are centered on solving real-world needs which is a primary mission of the creative profession of engineering

As pointed out in a 1995 National Academy of Sciences report, "Although it is clear that human resources are the primary key to the nation's strength in science and technology, we, have not, as a nation, paid adequate attention to the graduate schools as a system for meeting the full range of needs for advanced talent in science and engineering … There is no clear human-resources policy for advanced scientists and engineers, so their education is largely a by-product of policies that support research. The simplifying assumption has apparently been that the primary mission of graduate programs is to produce the next generation of academic researchers … If scientists and engineers are to contribute effectively to national, scientific, and technological objectives, their educational experience must prepare them to do so … There is room for substantial improvement in graduate education … and … graduate education must also serve better the needs of those whose careers will not center on research."[11]

5. PROFESSIONAL-ORIENTED GRADUATE EDUCATION FOR ENGINEERS IN INDUSTRY

Therefore, based upon this new understanding of needs-driven creative technology development, it is time to reshape graduate education for the nation's creative graduate engineers in industry. While the research-driven model of graduate education has served the nation well in the education of future academic researchers, it is now apparent that an alternative model of professional-oriented graduate education is required for industrial innovation for the majority of the nation's graduate engineers in industry who are pursuing non-research professional careers in the creative leadership of continual technological improvement and innovation in industry.

5.1 Beyond the "Technology is Applied Science" Paradigm

As de Vries has pointed out, it is now apparent that we are moving through a transition in higher education for the creative development and leadership of technology which is beyond the "technology is applied science" paradigm.[12] As Wulf, president of the National Academy of Engineering, has pointed out, "Engineering is not applied science" — nor are creative engineers applied engineering scientists. Wulf further noted that, "Science is analytic — it strives to understand nature, what is. Engineering is synthetic — it strives to create what can be."[13]

Whereas, Bush recognized that the primary responsibility for scientific progress is dependent upon that small body of high caliber men and women in the research universities and in the government research laboratories, who understand the fundamental laws of nature and are skilled in the techniques of scientific research, it is now recognized that the primary responsibility for the creative generation, development, and leadership of needs-driven continual technology improvements and breakthrough industrial innovations is dependent upon that small group of high caliber men and women in industry who understand the fundamental laws of nature and are skilled in the techniques of creative engineering development and responsible professional leadership — the nation's graduate engineers who actually do needs-driven creative technology development work and who must lead the future continual technology improvement and innovation process in industry. These in-place professionals are the originators, pacesetters and the creative lifeblood and "wellspring" for continual technological innovation in America's industry. It is now evident that the policy or lack of policy for professional-oriented graduate education for the nation's graduate engineers in industry and that of the nation's propensity for innovative technological competitiveness in the worldwide market are inextricably linked together.

5.2 Professional-Oriented Graduate Education: A Process of Lifelong Growth and Creative Experience

As with other types of leadership development, the professional education of the creative engineer-leader is a long-term growth process which extends over a professional lifetime. It is a continuous process of lifelong growth which begins in the early formative years of preparatory education; it continues through the pre-service years of entry level undergraduate engineering education; and, it continues throughout the professional years of actual creative leadership in engineering practice. Whereas the broad aim of undergraduate engineering education is to prepare men and women for entrance into the practicing profession and to lay the basic foundation of fundamentals for further graduate study, the aim of professional-oriented graduate education must be to continue the growth of the in-place graduate engineer, after entrance into the profession, toward his or her fullest creative leadership potential in professional practice.

As a long-term growth process, the educational growth of creative engineer-leaders is neither constrained to a four year pre-service undergraduate education nor to a five year education — it is a continuous process of lifelong growth and development of intrinsic potential which must be supported and nurtured throughout the graduate engineer's career in industry. However, as Deming pointed out, it is now apparent that traditional management principles of direction and control are no longer sufficient in facilitating the developmental growth and leadership of creative professionals in the continuous technological innovation process in industry.[14] It is also apparent that the traditional didactic concepts of education, as predominantly practiced at the universities in which conventional educational wisdom defines education as the transmission and acquisition of knowledge, are no longer sufficient in educating imaginative professionals for increasingly responsible innovative engineering work. In this context, as Maslow pointed out in 1971, education should no longer be viewed as merely a knowledge transfer process which involves the transmission and acquisition of knowledge from teacher to learner.[15]

5.3 Beyond the "Education is the Transmission and Acquisition of Knowledge" Paradigm

As Maslow observed, "… this means that we must teach and train engineers not in the old and standard sense, but in the new sense, as creative engineers … and … education can no longer be considered essentially or only a learning process."[15] Subsequently, although the emphasis of undergraduate engineering education is one of sequential learning for postponed application, which is primarily based upon a content-centered model of knowledge transfer and acquisition of knowledge, the emphasis of professional-oriented graduate education for experienced graduate engineers in industry must be one of concurrent learning and creative growth which must be based upon a content-process model of professional-oriented graduate education which involves not only learning and gaining technical expertise but also includes the development of responsible creative leadership capability which is required for responsible charge of meaningful creative technology development to meet real-world human needs or to create effective solutions for continuous industrial improvements.

Therefore, in order to further develop the intrinsic creative potential of engineer-leaders in industry for the highest levels of creative leadership, beyond pre-service undergraduate engineering education, it is apparent that we must transition beyond the "education is the transmission and acquisition of knowledge" paradigm. At this level of higher education, professional-oriented graduate education must integrate a content-process model of education concurrently with on-going experiential growth in creative engineering practice — a process of "learning-by-doing" in creative engineering work. Accordingly, the model of professional-oriented graduate education for creative engineers in industry must now be viewed as a working model that supports an integrative growth process which involves not only learning through formal instruction but also involves self-directed learning and inquiry to gain an in-depth knowledge and technical expertise of the organization's technology as well as involving experiential based growth through actual meaningful creative engineering work. In this sense the model of professional-oriented graduate education for in-place engineer-leaders in industry must be one that supports a continuous growth process which builds a synergy between higher education and continual creative technological innovation in industry.

5.4 Stages of Growth in Engineering Practice: Beyond Entry Level

Based on actual educational needs-assessment studies of in-place graduate engineers in industry, it is now evident that there are nine stages of growth, proficiency, and levels of responsible professional leadership in engineering practice beyond undergraduate pre-professional entry level education. These levels of growth range from beginning project engineer through executive engineer leadership levels of professional responsibility, value judgement, program making, and technology policy making.

As Wickenden noted, "… virtually all engineering problems fall on some one of three fairly distinct levels: (1) the level of known laws and data; (2) the level of technical judgment; and (3) the level of policy making." As Wickenden pointed out, undergraduate entry level engineering education prepares the young graduate for beginning professional work at the first level — additional progressive engineering experience and graduate professional education is necessary for the in-place graduate engineer to grow to higher leadership levels of engineering attainment and professional responsibility.[16]

Wickenden further observed that, "… The engineer graduate will do well to recognize that his training in college fits him only for the first of these levels. Training for the higher levels is yet to come. Most of it will be up to him. Experience together with specialization usually will carry him to the second level, but the time required and the area of coverage will depend largely upon the individual's interest and initiative. Experience and specialization alone will never carry him to the third level of responsibility. To reach it he will have to be qualified for a broader kind of thinking with more variables involved and many of them of a highly intangible character. Engineering consists not only in solving problems, but equally in making programs of execution. College teaches the rudiments of problem-solving, but little about program-making …" Wickenden also pointed out that, "… much more than technical specialization is involved in the higher levels of engineering attainment. … This job of program planning is one of intricate co-ordination … It is not taught at college … It is one of the major goals of an engineer's post-college education."[16]

5.5 Professional Dimensions of Creative Engineering Leadership for Technology Innovation

Thus, contrary to popular belief, creative professional engineering practice is not a linear follow-on process to research nor does creative technology development primarily exploit the results of scientific research in a linear manner. Creative technology development is a unique creative professional practice of engineering with unique professional dimensions. Whereas scientific research is analytic and uses the scientific method, creative technology development uses the engineering method in meeting real-world hopes, wants, and needs of people. Whereas scientific research starts with curiosity, creative engineering starts with an innovation ethic to deliberately and systematically meet real-world needs to improve the human condition.

Toward this aim, the professional dimensions for the systematic engineering practice and professional leadership of needs-driven innovation and technology development are now known. They include:

- technical competence,
- creative problem-solving, systems thinking, and innovation,
- professional responsibility,
- professional leadership of multidisciplinary groups for needs-driven collaborative creativity,
- problem finding and visualization (needs-finding),
- program making and strategic thinking,
- policy making, value judgement, ethics in technology-social-safety-economic issues.

6. CONCEPTUAL CLARITY FOR PROFESSIONAL-ORIENTED GRADUATE EDUCATION

The prospect is clear. Improvement of U.S. innovation and technological competitiveness is strongly influenced by improvement of the acquisition stage of technological capability. Today, it is known worldwide that technology innovation in industry is the driving force for innovative competitiveness and prosperity in the global economy. Creative engineering and the leadership of creative technology development in industry is just as important as scientific research. Key to improvement of this creative technological process is a nurturing industrial culture of leadership for innovation, and a nurturing university culture of professional-oriented graduate education that provides the opportunity and stimulation for the nation's in-place graduate engineers in industry to grow creatively and professionally.

6.1 Stimulate U.S. Economic Growth Through Graduate Education for Engineer-Leaders in Industry

It is now clear that the nation's primary "wellspring" for the generation, creation, innovation, and leadership of technology is the nation's creative human resource base of in-place graduate engineers in industry. Professional-oriented graduate education programs that are specifically designed and implemented to further the leadership growth and creative development of this vital national asset will directly and immediately stimulate effective innovation for improvement of U.S. innovative competitiveness in the worldwide economy. Therefore, the education of creative engineer-leaders can no longer be perceived or constrained to be predominantly at the undergraduate level nor can the nation any longer afford graduate education at the research universities to be perceived as or to be constrained predominantly as training for future teachers and academic researchers.

Therefore, as Whitfield has pointed out, it is taken as self-evident that the creative output of the nation's engineering strength will be increased most rapidly by successful efforts to improve the creativity of the engineer already in industry, specifically the engineer who has added an adequacy of experience to his or her basic technical training.[17] Correspondingly, the specific development and implementation of a professional-oriented graduate educational alternative which furthers the growth, learning, and creative development of the nation's in-place graduate engineers in industry can significantly improve U.S. technological competitiveness.

6.2 Making the Transition

As pointed out in the 1995 National Academy of Sciences study, it is now evident that the mission of graduate education must be broadened in order to improve creativity, flexibility, and versatility within the practicing engineering profession in industry, specifically for the majority of the nation's graduate engineers who are pursuing non research-oriented careers in the leadership of continuous improvement and of creative technology development in industry.[11] Therefore, it is timely and of great national importance, that innovative universities deliberately develop and implement professional-oriented graduate education programs for in-place graduate engineers — as innovators and leaders — who can nurture and develop the nation's future technological progress and U.S. competitiveness. However, this reform must be effected without disruption of the traditional commitment to excellence in basic research that has been, and must continue to be, a hallmark of the system of graduate education.

Whereas, attempts to provide five year programs at the master's level for young resident engineering students have been successful, they are not sufficient. Professional-oriented graduate education must be provided experienced graduate engineers in industry to enable these graduates to continue their growth to the highest levels of creative leadership in the engineering profession. It is recognized that there are nine stages of growth and leadership responsibility beyond undergraduate entry level pre-service education. As Cranch has pointed out, everything can't be taught in the already saturated undergraduate engineering curriculum, nor have undergraduate engineering students reached the level of professional maturity to grasp certain professional issues.[9]

Accordingly, the model of professional-oriented graduate education which is required to enable in-place graduate engineers in industry to continue to grow is neither a follow-on, nor is it a by-product of graduate education for research, nor is it simply an extension of content and method of pre-professional entry level undergraduate engineering education. In fact, professional-oriented graduate education for engineer-leaders in industry is quite different from graduate education for researchers because the aims are quite different, as are the professional maturity factors, experiences, and objectives of experienced in-place graduate engineers in industry. Many of the professional dimensions for creative engineering leadership cannot be developed until later years in graduate professional education and after the graduate engineer-leader has gained an established technical competency and an established in-depth industrial experience base in practice. From this perspective, there is now both the conceptual clarity and factual basis for broad national support and for implementation of high-quality professional-oriented graduate education for in-place graduate engineers in industry who are the nation's critical human resource for creative leadership of needs-driven continuous improvement and technology development in industry.

7. CENTERS FOR INNOVATION AND TECHNOLOGY LEADERSHIP

Therefore, the authors recommend that high quality regional centers be established across the nation between emerging universities and regional participating industry for professional-oriented graduate education for in-place graduate engineers in industry. The programs will complement the university research mission with meaningful needs-driven creative technology development and industrially relevant professional-oriented graduate education for graduate engineer-leaders in industry.

7.1 Vision and Mission

The collaborative centers will be national models for innovation and responsiveness in addressing the graduate professional engineering education, economic development and lifelong learning needs of their states. As models in the nation, the centers will serve as unique "teaching and technology development" centers for creative technological innovation and for high-quality professional-oriented graduate education for in-place graduate engineers in regional industry.

The mission of the professional-oriented graduate centers will be to foster the development of creative engineer-leaders in industry for responsible professional leadership of industry's future technology, and to foster the development of needs-driven technology innovation, and policy, responsive to meaningful industrial and societal needs. The centers will provide high-quality graduate professional education which will be specifically relevant to the developmental stages of growth and to the professional dimensions of responsible leadership in engineering.

7.2 Professional-Oriented Graduate Education for Engineers in Industry: Concurrent Advanced Studies Integrated with Engineering Practice in Industry

The regional centers will build upon a new concept of professional-oriented graduate education which is more conducive to the manner in which advanced practicing professionals learn, grow, and develop in engineering practice and which combines advanced studies in technology leadership concurrently with the graduate engineer-leader's on-going experiential growth in actual creative technology development work in industry. As models in the nation, the centers will provide experienced in-place graduate engineers in industry the opportunity and learning organizational climate to continue their growth, learning and creative leadership development as they assume increasing professional leadership responsibility of meaningful needs-driven creative engineering work.

Because responsible leadership of needs-driven creative technology development in industry is a unique professional engineering practice and responsibility, the graduate professional education of creative engineer-leaders is more than simply combining traditional business courses with traditional engineering courses. Consequently, the program of advanced graduate studies will build upon three modes of human resource development in the professions.[18] They include: (1) self-directed learning and inquiry; (2) industrially relevant professional-oriented graduate education; and (3) actual creative professional leadership of needs-driven continual improvement and creative technology development in industry.

The centers will provide experienced in-place graduate engineers in regional industry the opportunity to continue their postgraduate professional education and growth while employed full-time in industry and while pursuing leadership of creative technology development work. Recognizing the unique blend of technical, professional, ethical, creative, and leadership dimensions, the initiative will set a new direction in professional-oriented graduate education. The program of professional-oriented graduate education will not be intended to serve as a "stepping stone" along the research-oriented path of graduate education, but rather as a path of excellence in its own right toward the highest creative leadership levels of professional engineering practice — through the professional master's level, the professional doctoral level, and beyond, for responsible professional leadership of technology in industry.

7.3 Professional-Oriented Graduate Education for Engineers in Industry:
Concurrent with the Stages of Growth and Professional Dimensions of Engineering Leadership

The centers will provide a professional-oriented graduate educational alternative for industrial innovation that supports the process of developmental growth for the majority of the nation's graduate engineers in industry who lead the continual technology innovation process. The curriculum will be specifically designed for experienced in-place graduate engineers who are pursuing responsible professional leadership careers, which are not centered on research, but which are centered on creative engineering leadership for continuous improvement and innovation of products, processes, systems, and operations responsive to real-world industrial and societal needs.

The curriculum will be planned to meet already assessed educational needs of the practicing profession in industry, and to be commensurate with the professional dimensions of creative engineering leadership, Accordingly, the professional-oriented curriculum will be specifically designed as a matrix of advanced graduate studies which will coherently match and support actual assessed educational growth needs of engineer-leaders in industry; the professional dimensions of creative engineering practice; and, the nine stages of developmental growth of increasing responsibility for leadership of technology, beyond entry level undergraduate engineering education — from project engineer level through executive leadership policy levels of engineering responsibility.

7.4 Professional-Oriented Graduate Education for Engineers in Industry:
Linking Professional Education with Continual Technology Innovation in Industry

The program's emphasis will be on "doing-centered" experiential based growth and continued development in practice. The program will combine industrially relevant advanced graduate studies with the engineer-leader's creative technology development work in industry. In this manner, the centers will directly enhance U.S. technology competitiveness by linking higher education with continual technology improvement and innovation in industry.
Accordingly, the integrating component of the professional-oriented graduate curriculum will be a needs-driven creative technology development project-thesis. Whereas the model of research-oriented graduate education is organized around an intensive research thesis experience, the model of professional-oriented graduate education will be organized around an intensive creative technology development project-thesis experience in industry which will be directly relevant to societal or sponsoring industry's needs. The technology development project-thesis will serve to integrate the curriculum of professional-oriented graduate studies with the creative practice of the graduate engineer-leader in industry. As Pettit and Gere pointed out in 1968, a thesis offers an opportunity for the participant to engage in a creative self-learning experience, and hence it can perform a vital role in his or her education.[19]

7.5 Professional-Oriented Graduate Education for Engineers in Industry:
Developing Technology in Industry and Developing Engineer-Leaders in Industry Simultaneously

The centers will build upon a unique international concept for industry and higher education. Worldwide experience shows that developing technology in industry and developing future creative engineer-leaders in industry simultaneously is a very effective way of increasing industry's capacity to innovate effectively. It is now recognized worldwide that in order to contribute most effectively to industrial innovation and the creation of wealth, graduate engineers need to continuously develop their leadership skills as well as their technical knowledge and theoretical understanding throughout their careers. This requires an educational approach at the graduate professional level which is not only driven by the satisfaction of real industrial needs but also is commensurate with the stages of growth and the professional dimensions of engineering leadership.[20]

As Conrad, Haworth, and Millar have been pointed out, in a national study for the Council of Graduate Schools, "… a primary attribute of high-quality graduate experience is that the participants produce a tangible product, thesis or project report, which is of some value to the field as well as to them personally."[21] Thus, a tangible project-thesis or project report in industry has proven to be a significant factor in high quality graduate education. This innovative focus will require a cadre of experienced professional-oriented faculty working in thesis supervisory roles with high caliber adjunct counterparts in industry, as it would be unfair to impose this workload upon the already over-burdened academic research-oriented faculty who have other research interests and other reward systems.

7.6 Professional-Oriented Graduate Education for Engineers in Industry:
Supporting Creative Technology Development In Industry Beyond Technology Transfer

Accordingly, a primary attribute of the centers' emphasis for innovative high quality professional-oriented graduate education will be a tangible project- thesis focused in the technological field of the graduate engineer's innovative work. Consequently, during the program of advanced graduate studies, each professional participant will identify a meaningful real-world societal need or industrial problem of importance to his or her sponsoring organization, and will work in collaboration with principal professional-oriented faculty members who will help guide the thesis-project work in dual supervision with industry.

This practice-oriented approach will provide both industrial sponsors and emerging creative engineer-leaders an excellent method by which to study industrial issues and to stimulate creative leadership for continual technological innovation relevant to real-world industrial or societal needs. Whereas research-oriented graduate education builds upon the synergy between research and graduate education, professional-oriented graduate education can build upon the synergy between genuine needs-driven creative industrial innovation and industrially relevant professional-oriented graduate education. The needs-driven creative project-thesis provides this synergism for high-quality graduate professional education and continual needs-driven creative technological innovation in industry. The spin-off effects of these creative technology development projects, conducted in industry and at graduate centers across the nation, will directly and immediately enhance U.S. innovative competitiveness and the nation's creative technological infrastructure in industry many-fold.

7.7 Professional-Oriented Graduate Education for Engineers in Industry:
Supporting Lifelong Growth and Creative Leadership in the Engineering Profession

The thrust of the graduate centers will be to foster national leadership in innovative professional education which will specifically support professional-oriented graduate education as a lifelong process that nurtures and supports the intellectual growth, ethical, technical, and creative-leadership development of the engineer-leader toward his or her fullest potential for responsible professional leadership in the practicing profession in industry. The overall aim will be to provide an integrated professional -oriented program of graduate studies to develop versatility, creativity, technical competence, flexibility, and innovative capabilities which are needed for the in-place graduate engineer in industry to grow in responsible creative leadership of meaningful creative engineering work.

The program will built upon the premise that the professional education of engineers is not a one-time event which is completed in the years prior to employment. It is now recognized that the professional education of an engineer-leader is a continuous process of lifelong growth and involving increasing responsibility, in which both creative engineering experience and professional-oriented graduate education are necessary. Therefore, the centers will offer professional-oriented graduate education for in-place engineers in industry through a dynamic and open-ended curriculum which fosters the developmental growth of the in-place graduate engineer through the professional master's level, the professional doctoral level, and on the highest levels of creative leadership within the practicing profession.

7.8 Professional-Oriented Graduate Education for Engineers in Industry:
Supporting A Continuous Creative Growth Process Beyond Knowledge Transfer

Today, professional-oriented graduate education should no longer be viewed merely as preparation for practice, to be done in the early years of a young professional's education nor merely as an information transfer process from university to industry or from teacher to student. Rather, professional-oriented graduate education must now be viewed as a continuous growth process which is concurrent with on-going practice in industry and which promotes career-long growth of the nation's creative engineer-leaders — from project engineer through executive engineering leadership policy levels of responsibility — whereby industrially relevant professional master's education and industrially relevant professional doctoral education are supportive stages of growth in a professional's continuous growth process in industry.

From this perspective, learning does not merely mean acquiring more information, but rather it includes the concept of expanding the intrinsic creative leadership potential of the creative professional to achieve creative engineering results. As Senge has pointed out, this may be viewed as lifelong generative learning — in which appropriate learning organizational cultures are required to nurture this process.[22] Based on this recognition, the graduate professional curriculum for technology leadership will build upon undergraduate engineering education as the basic educational foundation of fundamentals which prepares young graduates for the practice of engineering at the first entry professional level. The program of professional-oriented graduate studies will be specifically intended to continue the advanced professional education of in-place graduate engineers in industry who have a minimum of at least two years of actual engineering experience beyond their undergraduate degree affording them the opportunity to continue their growth and professional development commensurate with their full-time employment in industry. The centers will provide a very cost-effective and feasible way in which to build high-quality and innovative professional-oriented graduate education programs of excellence. These professional programs will complement existing graduate research-oriented programs; adding revenue, national prestige, recognition, and strength to the associated universities.

7.9 Professional-Oriented Graduate Education for Engineers in Industry: The Market Need Across the Nation and Internationally for Education for Engineer-Leaders in Industry

The centers will meet a long felt industrial need which has been a missing component in the nation's efforts to continually improve U.S. innovative competitiveness and to improve the nation's creative technological infrastructure in industry. Accordingly, the concept model of professional-oriented graduate education is based on the realism that most of the nation's graduate engineers are recruited by industry and then enter industry immediately after their pre-service entry level undergraduate engineering education.

However, if they are afforded the opportunity to do so, these graduate engineers want to continue their growth in first rate professional educational programs throughout their careers. As Conrad, Haworth, and Millar have pointed out, it is now known that graduate education in the United States is already in transformation.[21] There is a "continuing wave" of nontraditional graduate professional students whose educational growth needs and professional experiences are quite different from those of traditional young resident graduate students who are pursuing careers in academic research and teaching. Based on the results of the national study of graduate education, it is now evident that at the master's level over 90% of the participants are in the professional fields outside the traditional liberal arts and sciences. And over 50% are in the professions at the doctoral level. It is also now evident, as the national graduate study pointed out, that "… about one-half of all master's students are thirty years of age or older, and two-thirds are enrolled part-time."[21]

The program of professional-oriented graduate education for engineers in industry will be purposefully designed to continue the growth of this new clientele — it will be specifically designed for career long growth for creative leadership in engineering after the young graduate engineer enters industry. The market need is significant and is both national and international in scope. As engineering executives have pointed out, relevant professional-oriented graduate education for engineers in industry is a critical missing component that can have significant impact on U.S. innovative competitiveness and on the nation's future economic growth.

8. STRATEGY FOR IMPLEMENTATION

Therefore, it has become evident that universities must serve two vital functions in higher education at the graduate level: (1) to be centers of excellence in graduate education for scientific research which promote the continual advance of science and our understanding of natural phenomena and to educate future academic researchers; and, (2) to be centers of excellence in professional-oriented graduate education which educate creative professionals for innovation and leadership in the professions, and which continually promote creative professional service, innovation, and leadership responsive to meaningful real-world societal needs.

8.1 Transition to Professional-Oriented Graduate Education for Engineers in Industry

Thus, universities must stand as cathedrals of learning and human resource development, serving not only to educate future academic researchers, but also to educate future creative leaders in the professions, such as in engineering. Now more than ever, the nation's research universities must reassess their professional education mission and set a new direction more responsive to the growth needs of the professions whose mission is to meet real-world societal and industrial needs.

However, it would be naïve to believe that research universities would make this needed transformation and organizational cultural change in engineering education without resistance unless it is clearly perceived to be in their best interests to do so. There are several reasons for this reluctance. The first of these is that the transformation is not in the primary interests of the research-oriented faculty nor does it fit nicely into traditional engineering disciplinary departments. The second of these reasons is that the transformation does not fit into the scheme of federal research-oriented funding nor does it fit into the existing tenure-promotion reward structure for research-oriented faculty to publish in scientific journals or to attract federal research monies. It must be acknowledged that professional-oriented graduate education for engineers in industry is different from graduate education for research and it serves a different mission and clientele of professionals who are not researchers but who are emerging creative engineer-leaders in industry in which the fullest development of this vital creative human resource is critical to the nation's continual technological progress and economic prosperity.

8.2 Resistance to Transformation

After three decades of primary emphasis on research, the transformation to include industrial relevant professional-oriented graduate education for engineers in industry will neither be easy nor will it occur without resistance. Although a transformation has already begun at the undergraduate level with increased emphasis placed upon engineering design projects and teams, the major area for transformation in engineering education is at the graduate professional level because the longest duration of an engineer-leaders continuous growth process is the period of postgraduate professional education during the professional years.

Realistically, the transformation which is required in professional engineering education at the graduate level will probably receive lukewarm support from the majority of research-oriented faculty. Specifically, as Pettit and Gere pointed out, thesis supervision requires a considerable amount of faculty time.[19] The judicious use of faculty supervision is a limiting constraint in high quality graduate education and this constraint is too frequently reflected at research universities in cases where the professional master's degree too often has taken a second-ranked place within a research faculty's understandable primary emphasis on their "own" sponsored research and on their "own" resident graduate students.

Faculty supervision of creative technology development project-theses will definitely require a considerable amount of time and effort in which faculty must be compensated accordingly. However, this should not be viewed as a hindrance, but rather as a strength of high-quality professional-oriented graduate education which is needed to improve industry-university interaction for economic development and to continually improve U.S. innovative competitiveness. Implementation of first rate professional-oriented graduate education at the nation's research universities will require planned change and collaborative educational leadership so as not to threaten predominantly research-oriented cultures, curricula, and faculty but to complement them with professional-oriented graduate centers to provide national leadership in innovative engineering and in graduate professional education for leadership of technology. This will require a collaborative partnership between universities, industry, and government for economic development and for continuous improvement of U.S. competitiveness.

There are six key issues which need to be addressed for this transformation to be successfully implemented and sustained in the mainstream of university operations. These issues are not sequential but will require simultaneous action in the implementation process. They include:

- Modification of criteria for tenure-promotion of professional-oriented faculty.
- Provision of sustained funding for high quality professional-oriented graduate education.
- Provision of sustained funding to support continuous improvement and educational innovation of the program.
- Provision of collaborative oversight between universities and the practicing profession in industry for continuous curricula development and improvement.
- Formation of and provision for continuous development of an experienced professional-oriented faculty.
- Provision for collaborative faculty-industry interaction in supervision of meaningful technology development thesis projects — a dual role between university faculty and distinguished adjunct faculty in industry.

8.3 Building Upon the Combined Strengths of Industry and the University

To implement this transformation in times of tight budgetary constraints, the centers will build upon the existing facilities and professional-oriented faculty strengths within the university in collaboration with the technological strengths and engineering strengths within regional industry. One of the critical ingredients for implementation of this initiative in innovative education will be the recruitment, development, and continual support of an experienced professional-oriented faculty consisting of a resident cadre of principal faculty from engineering together with other distinguished faculty from within the total university system. These faculty will join a cadre of experienced adjunct faculty who have distinguished themselves as creative engineer-leaders and innovators in industry.

This unique multidisciplinary and experienced faculty base consisting of both technical and engineering leadership expertise would form one of the strongest professional-oriented faculties in the nation and would strongly complement the existing graduate research-oriented academic base. The centers' organizational culture would encourage collaborative faculty creativity in teaching and in technological innovation across departmental and university boundaries, between participating universities, and with sponsoring industries. Such an organizational approach has the potential to draw experienced engineers from the practicing profession to build one of the strongest professional-oriented faculty in the nation with industry's help and sponsorship. This strategy also facilitates building upon the unique synergy of technological and scientific facilities that currently exists within the nation's research universities and within constituent regional industry.

8.4 Building Upon the Strengths of the Graduate Engineer-Leader Participants in Industry

The second critical ingredient for implementation of this unique initiative in innovative education will be the recruitment, development, and continual support of a professional-oriented practicing student body drawn from the regional practicing profession of in-place graduate engineer-leaders in industry. These high caliber participants would have the creative leadership potential and intrinsic motivation to continue to grow and become leaders, developers, and innovators of industry's future technological progress and competitiveness.

Toward this aim, the program will be specifically designed to foster the professional growth of experienced graduate engineers in industry who have a minimum of at least two years of experience in industry, beyond their undergraduate engineering education, and who are growing as creative leaders of technology. The program will not be designed for graduate students either just out of college or wishing to remain in graduate school to pursue graduate research-oriented education. Rather the program will be designed to continue the growth, learning, and creative development of the in-place experienced graduate engineer in industry to higher levels of competency, creative leadership, technical, ethical, and professional maturity. The program will extend to the highest creative leadership levels of professional practice for the responsible engineering leadership of technology.

Because most industries recruit high caliber graduate engineers from among the nation's various universities, the centers will enable these high-caliber graduate engineers in industry to continue their advanced professional educational growth while employed full-time in industry. Consequently, this experienced practicing graduate professional student body will reflect one of the nation's finest and strongest professional-oriented groups of experienced engineers who are continuing their growth in the engineering profession for creative leadership roles in industry — and, who are the nation's technology leadership base for continual improvement of U.S.

competitiveness in the worldwide economy. From this perspective, the program will not detract from either the quality or the research-orientation of the university. Rather, it will add a unique professional quality strength, additional revenue, and national prestige.

8.5 Partnership for Economic Development

Accordingly, there is now both the conceptual clarity and the factual basis to develop and implement an alternative program of high-quality graduate professional education for the nation's in-place graduate engineers in industry who are critical to leadership of the nation's future technological progress, competitiveness, and economic development. However, with the existing constraints of tight operating budgets and noticeable faculty emphasis on solicitation for sponsored research funding, universities can not make this transformation from within.

This transformation can be made at the nation's universities, however, through a unique partnership between the universities, industry, and government with neither disruption nor loss of integrity of a university's research mission which is a "hallmark" of traditional graduate scientific education. A program of state and national support to develop and implement this graduate professional alternative for in-place graduate engineers in industry, beyond their formal first degree education, as innovators and leaders of technology can have significant and immediate direct returns and benefits to continual improvement of U.S. innovative technology competitiveness and to the attractiveness of participating states for continual economic development.

This initiative in innovative professional engineering education will require a partnership for economic development between state government, federal government, industry, and universities as an investment in the professional education and the continual growth of creative engineer-leaders in industry who are the primary generators, innovators, and leaders of the nation's future technological progress. This modest investment in innovative education can be very cost-effective with significant returns to all who are stakeholders in the nation's continual technology innovation enterprise.

8.6 Creating Collaborative Advantage for Leadership and Diversity in Innovative Education

As with major transformations and innovations, the building of a creative collaboration among competent creative people with shared vision, mission and purpose is essential for implementation and sustainability of innovative education in university operations across the nation. Now more than ever the nation needs collaborative educational leadership to rebuild high quality professional education into the nation's research universities. No one university can do this job alone in the initial developmental and implementation phases of this innovative initiative. Nor should they be required to do so without drawing upon the high caliber of educational leadership, experience and wisdom which is available in sectors of professional educational across the nation.

Therefore, a primary strategy for the successful development and implementation of this initiative for national leadership in innovative engineering education will be to build a strategic national and international alliance between a few key emerging universities working together in creative collaboration for educational leadership to "champion" the concept in their regions and their nations for economic development. Key to the strength of this collaboration will be the trust and the diversity for leadership in innovation within a shared vision and mission to bring forth high quality industrially relevant professional-oriented graduate education for the nation's creative engineer-leaders in industry and to provide national educational leadership to support needs-driven creative technological innovations which occurs in the nation's industry.

9. CONCLUSION AND NEXT STEPS FOR IMPLEMENTATION

It is now clear that there are two distinct types of education and cultures at the graduate level: (1) graduate scientific education for research; and (2) professional-oriented graduate education for responsible service and creative leadership to meet meaningful real-world societal needs. These have different missions, purposes, participants, faculty, curricula and methods. Without diminishing the importance of research-driven technology, it is now understood that continual needs-driven improvement and creative technology development in industry is the primary driving force for the nation's technological progress. The nation's primary human resource for the creative generation, development and leadership of needs-driven technology innovation is the nation's in-place graduate engineers in industry. Currently, there is no coherent educational policy for the graduate education of the nation's engineers. Their graduate education is primarily a by-product of a national educational policy which supports research because of the singular research-driven model of technology.

It is now recognized that graduate education must also serve better the needs of those professionals whose careers are not centered on research, but rather are centered on solving real-world human needs which is the mission of the creative profession of engineering. While general support for research-oriented graduate education programs has been underway in the United States for over three decades, it is now compelling and timely to build and implement professional-oriented graduate education programs into the nation's graduate education and technological infrastructure. There is now both the conceptual clarity and factual basis to establish an alternative of high-quality graduate professional education for the nation's in-place graduate engineer-leaders in industry who are critical to leadership of the nation's future technological progress and competitiveness. This transformation can be made at the nation's universities through a unique partnership between the universities, industry, and government with neither disruption nor loss of integrity of the research mission which is a "hallmark" of traditional graduate scientific education. A program of general support to continue the graduate professional education of in-place graduate engineers in industry, beyond their formal first degree education, as innovators and leaders can have significant and immediate direct returns and benefits to improvement of U..S. innovation and technology competitiveness. It is now timely and appropriate to implement this initiative in innovative education with industry's thrust for continual creative technological innovation.

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