AN INTEGRATIVE APPROACH TO TEACHING AND LEARNING AT THE PROFESSIONAL LEVEL FOR GRADUATE ENGINEERS IN INDUSTRY

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1. INTRODUCTION

While traditional engineering education and graduate outreach programs are primarily based on the didactic approach to teaching and learning, namely the transmission and acquisition of knowledge, it is now apparent that an educational transformation and a different approach to teaching and learning is needed at the advanced professional level for graduate engineers in industry. At present, graduate education in engineering is primarily a byproduct of research, based on a science-driven model of technology, largely set in place in 1945 by the Bush report, "Science: The Endless Frontier."[1]

It is now apparent, after 50 years, that this model is only partially correct. Based on a new understanding of the technology innovation process, it is now evident that technology innovation is primarily a deliberate and systematic needs-driven process using the creative engineering method. While research-driven graduate education has served the nation well in the education of future academic researchers, it is now recognized that a different graduate education alternative and approach is required for the majority of the nation's graduate engineers in industry who are pursuing non-research professional career paths in the leadership of needs-driven innovation and technology development.

2. FRAMING THE ISSUES

Education means different things to different people. The lack of an appropriate definition of education for human resource development has limited the advancement of professional education at research universities and their fullest interaction and contributions to industry. Specifically, reference is made to the further advanced professional education of the nation's in-place graduate engineers in industry who are vital to improving industry's innovation and technological competitiveness.

2.1 Graduate Educational Policy and Scientific Research

Traditionally, the model of professional education for graduate engineers derives from the concept of research-driven knowledge transfer and learning at the universities, and subsequent application in professional practice by the practitioner. This concept of education is the result of the linear science-driven model of technology. The existing policy for graduate science education in the United States was basically established in the Bush report[1] to the president which outlined a program for continual technological progress after World War II. This report was a landmark, and it set the stage for national investment in postwar scientific research and graduate, research-oriented education that led to America's rise in graduate scientific research.

The Bush report built heavily on four main themes. First, that technology is science-driven and flows from basic research, which is the foundation upon which all technical progress is ultimately built. As 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." Second, 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." Third, that to ensure technological progress, the federal government was obligated to ensure basic scientific progress and should invest in the graduate research-oriented education of its future scientists. Fourth, 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 future technology and its future scientists.[1]

2.2 The Traditional Model of Education

Graduate research education, funding, research faculty, and curricula to enrich the graduate scientific research path was largely built into the nation's engineering schools in the 1960's, 70's and 80's. Consequently, American engineering education has primarily patterned the science-driven model of graduate education that is in-place at the graduate level at the nation's research universities. The universities have performed an outstanding job in meeting the science education and research goal. Those graduate engineers who are pursuing scientific research career paths have been especially well served.

The effects of the Bush report have been pervasive throughout 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 scientific research-driven technology. In the same context, the National Science Foundation (which Bush founded) has defined for several years 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 scientific research and education model for the professions has evolved as:

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

2.3 The Didactic Approach to Teaching and Learning

Correspondingly, because of the science-driven model and the research orientation of the faculty most undergraduate engineering education programs, and outreach graduate engineering education programs across the nation are based on the didactic approach to teaching and learning. As Knowles points out, conventional theories of learning view education primarily as schooling and as an instructional process involving the transmission and acquisition of knowledge, from teacher to student.[2]

Based on recent findings by the Council of Graduate Schools, "…In those programs in which faculty and program administrators chose a didactic approach, we learned that they embraced a generally authoritative view of knowledge coupled with a transmission model of communication." [3] The study further noted, that "… Faculty and students who adopted a didactic approach to teaching and learning enacted traditional, largely hierarchical, teacher and student roles. In defining themselves as "authoritative experts," faculty assumed responsibility (individually and collectively) for determining program and course content and transmitting knowledge to students … faculty primarily cast students into a receiver role in which they expected students to concentrate on acquiring and "storing" knowledge for later use. In turn, communication was largely hierarchical and one-way …" The study further indicated, that "Faculty and administrators using a didactic approach grounded most of their program's primary learning experiences in lectures and lecture discussions. Many faculty members communicated to us that this approach — interspersed with periodic evaluations to ensure that students achieved mastery of the material presented to them — was their preferred method for transferring knowledge to students. In most of these programs, faculty treated laboratory, clinical, and fieldwork experiences as supplementary learning activities that reinforced students' mastery of the knowledge transmitted to them."[3]

3. NEEDS-DRIVEN TECHNOLOGY INNOVATION

After three decades, higher education at the engineering schools is still primarily tied to the singular linear research model of science-driven technology development and the didactic approach to professional education. 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 teachers and academic researchers. At present, the graduate education of engineers has basically evolved as a byproduct of educational policy for scientific research.

3.1 Needs-Driven Model of Innovation and Technology Development

Although the Bush plan has proven to be correct for excellence in scientific research and graduate science education at the nation's research universities to promote the nation's scientific progress, it is fundamentally in error for innovation and development of the nation's future technology and for the professional education of its graduate engineers in industry to promote technology progress to meet real-world societal needs. The Bush report, with all of its evidence and rightful justification for national investment in basic scientific research, was only partially correct. It misled the president and the nation because it virtually ignored the multitude of effective technologies generated by the nation's graduate engineers in industry and government service, which was brought forth through the needs-driven creative engineering method for responsible leadership of innovation and technology development.

Findings presented in the U.S. Department of Defense study, "Project Hindsight", indicate that innovative technology development is primarily a deliberate and systematic needs-driven creative practice of engineering.[4] The purpose of the investigation was to determine the contributions of the science-driven approach and of the needs-driven engineering approach to America's acquisition of military systems technology capability. The findings of the study are that the key contributions to military systems technology since 1945 are: basic scientific research contributed 0.3%, applied research 7.7%, and needs-driven creative engineering development contributed 92%. Of this work, 49% came from industry, 39% came from Department of Defense government laboratories, 9% came from the universities, and 3% came from other agencies.

The lessons learned from Project Hindsight apply directly to civilian needs-driven technology development as well. The lessons learned are threefold. First, that technology progress in wartime or peacetime is accelerated by real needs and the flow of new ideas which help to create solutions to these needs. Second, that there are two primary approaches to the acquisition of new or improved technological capability; the science-driven approach and the needs-driven creative engineering approach. Of the two primary approaches, the "lion's" share of technology is generated by deliberate and systematic needs-driven creative engineering development from exploratory development for proof of feasibility and concept through advanced engineering systems development for operational quality and capability, for cost-effectiveness, safety, environmental protection and customer use. Third, that the primary source of the nation's future technological capability for economic growth, improvement in the quality of life, and for ensuring national security is the nation's human resource base of creative graduate engineers in industry and government service.

Consequently, it is now recognized in the United States, and in other nations, that the pursuit of scientific research and the pursuit of needs-driven innovative technology development are two distinct activities and processes with distinct missions.[5] They are not linear events. The purposes, methods, and talents of the people who engage in these endeavors are normally very different. As Martino points out, "… there is no neat linear progression from one into the other, as the traditional model implies."[6] Accordingly, it is now recognized that the singular academic research-driven model of technology generation and graduate education, which the United States has built its civilian oriented science and technology goals for the furtherance of the nation's general welfare, is incomplete and insufficient to maintain America's innovative technological competitiveness in the world economy. The model of scientific education for research investigation, analysis, and discovery, and the model of professional education for creative engineering development, and professional leadership, are two discrete types of higher education because their missions, purposes, and methods of activity are different. As Walker, chairman of the ASEE goals report and former chairman of the National Science Foundation Board, pointed out in 1978, "Teaching research isn't teaching engineering."[7]

3.2 Two Paths of Excellence: Scientific Research and Discovery And Creative Professional Engineering Practice for Technology Development

A misunderstanding of the primary method for acquisition of new technological capability exists. There is no doubt that both the exploitation of scientific research and the deliberate needs-driven creative engineering development of technology are both useful approaches in the acquisition of technological capability. However, as Ferguson has noted, the resistance to the awareness and recognition of the bifurcation of academic scientific research and of real-world professional engineering practice for needs-driven technology development has been enormous.[8] As Ferguson has observed, "… From Bacon's time to the present — more than 350 years — promoters of the mathematical sciences have convinced their patrons that science is the way to the truth and that it is also the chief source of the progressive inventions that have changed the material world .The myth that the knowledge incorporated in any invention must originate in science is now accepted in Western culture as an article of faith, and the science policies of nation's rest on that faith."[8] As Ferguson noted, the Bush report "… restated the myth." [8]

During the last three decades, America has built its science policy and national goals for civilian technology development on this belief system.[10] However, during this same time period America has built its preeminent military systems technology development approach on the more effective needs-driven model of deliberate goal-oriented systematic technology development for mission oriented departments (e.g. The United States Air Force) using the systematic practice and needs-driven creative engineering method, from exploratory development through advanced engineering systems development of complex systems.

4. ADVANCED PROFESSIONAL EDUCATION FOR ENGINEERS IN INDUSTRY

After three decades the need to rebuild the professional education dimension at the nation's research universities has now shown up as a national priority to improve U.S technology competitiveness. As pointed out in the 1995 National Academy of Science report, it is now apparent that while scientific research is a "hallmark" of American graduate education that another graduate alternative is needed to build industrial creativity, flexibility, and versatility at the graduate level in order for professionals who are pursuing career paths not centered on research to handle new problems of increasing complexity to meet real societal needs in a proactive manner. [11]

As the 1995 NAS report pointed out, "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 byproduct 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."[11]

As the report stated, "In view of the broad range of ways in which scientists and engineers contribute to national needs, it is time to review how they are educated to do so." In this context the report clearly noted that most graduate engineers are pursuing non-research careers. Consequently, "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 … but graduate education must also serve better the needs of those whose careers will not center on research."[11]

4.1 Differentiating Characteristics Between Graduate Education for Scientific Research and Graduate Professional Education for Engineering Leadership of Technology Development

There are distinct differences between the mission of scientific research to discover and the mission of the engineering profession to create and provide professional leadership to serve mankind. Graduate scientific education for future academic researchers and graduate professional education for in-place graduate engineers in industry differ not only in their aims but also in their models of education, their knowledge base and in the types of abilities to be developed. Correspondingly, the methods and approaches for the graduate education of those who engage in these endeavors are not identical because of the differences of these two career paths.

As Whitehead observed, "A scientific education is primarily a training in the art of observing natural phenomena, and in the knowledge and deduction of laws concerning the sequence of such phenomena."[13] Graduate scientific education for research is focused on specialization in a scientific discipline and on the educational development of abilities of scientific investigation and analysis to discover in order to add on to the body of scientific knowledge, and to gain a better understanding of physical phenomena about the world and universe around us. Consequently, traditional graduate research education is based primarily on a content-centered model of education. However, as Whitehead observed, no man or women of science learns just in order to know; they know in order to discover.[13]

Professional engineering, however, serves a different purpose. In this context, the conventional wisdom that defines engineering as "applied science" or as the process that transforms scientific knowledge into new technologies (as the science-driven model indicates) is limiting and outmoded. Engineering can be defined, in a broader context, as "…a creative profession concerned with the combining of human, economic, and material resources to meet the needs of society … for the advancement and betterment of human welfare." Also, technology can also be defined in a broader context, "… as any systematic, organized body of applicable interrelated concepts (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)[14]

Accordingly, there is a distinctive difference between a scientific education for research and a professional education for creative engineering practice and responsible leadership. As Hollister pointed out, the distinguishing characteristics that differentiate a professional education in engineering from a scientific education for research is the creative engineering method and the educational development of the creative abilities of conceptualization to meet these real-world needs and to implement their creative solutions in a responsible professional leadership manner.[15] Accordingly, advanced professional education is based on a content-process model of educational development to educate competent practitioners in the ways to solve real-world societal needs that have previously gone unmet or have not previously been recognized. This type of professional education includes development of technical competence as well as the development of intrinsic creativeness and leadership potential.

4.2 Human Resource Development:
Concepts for Learning, Growth, and Creative Development

While the content-centered didactic approach to traditional teaching and learning has its rightful place in entry level undergraduate engineering education, and in graduate scientific education for research, it is now apparent that the graduate education of in-place professional engineers requires a different model and a paradigm shift to a content-process model of education because of the stages of professional growth of in-place graduate engineers, their increasing professional maturity, their wealth and diversity of engineering experience, and because of the increasing responsibilities and dimensions of professional practice. A transformation of organizational culture,[16] style of educational leadership and teaching is needed in advanced professional education because it is now evident that the traditional principles of organization, supervision, and teaching are incongruent with the developmental growth needs and the actualization of mature graduate engineers in industry who are pursuing professional leadership careers.[17]

Advanced professional education can no longer be viewed as a singular event of instruction and second hand textbook learning of existing knowledge with postponed application in practice. Rather, advanced professional education must now be viewed both in a knowledge context as a process of learning relevant knowledge with immediate application in professional practice and in a professional context as a continuing developmental growth process which includes the further development of technical competence, intrinsic creativeness, wisdom, value judgement, strategic systems thinking, program-making and policy making with professional responsibility. It is now known that competent graduate engineers in industry and government service don't practice their knowledge. They practice needs-finding, problem-solving, program making, policy making, and leadership with professional responsibility. "This means that we must teach and train engineers not in the old and standard sense, but in the new sense, i.e., "creative" engineers… and … education can no longer be considered essentially or only a learning process."[18]

4.3 Graduate Professional Education:
Education for Lifelong Growth, Leadership, and Creative Professional Practice

Contrary to conventional wisdom, education is more than a learning process from teacher to student. It is a developmental process of growth, which includes the development of intrinsic creative human potential. Whereas, traditional education in the United States is viewed primarily as the transmission and acquisition of knowledge and behavioral modification, it is now understood that the traditional perspective of education as schooling at the advanced professional level is limiting in scope. It has limited the fullest growth and development of the nation's creative engineering resources, causing not only the perception of early obsolescence but also the minimal development of professional leadership and innovative potential of the nation's in-place graduate engineers in industry. Consequently, it is both timely and of compelling national interest to build a graduate education alternative that nurtures the development of in-place graduate engineers for professional leadership roles in engineering throughout their professional careers.

Wickenden[19] observed that most creative engineering work falls within three primary levels: (1) the level of known laws and data; (2) the level of technical judgement; and (3) the level of value judgement. Further, he noted that undergraduate entry level engineering education prepares the young graduate engineer for beginning professional work at the first level. Additional advanced professional education and experience is necessary for the graduate engineer to grow to the higher leadership levels of the engineering profession. Accordingly, the education of graduate professionals for engineering leadership of needs-drive creative technology development is a long-term growth process, which extends throughout the practicing professional's career. It is not a one-time event. Neither is this developmental growth process constrained to four, five, or eight years. Based upon assessment studies of graduate engineers in industry and government service, it is now recognized that there are nine stages of growth, proficiency, and responsible engineering leadership for needs-driven technology development, beyond the undergraduate entry level — from beginning project engineer through executive engineering leadership levels of technological responsibility, value judgement, and technology policy making. The model of advanced professional education for in-place graduate engineers in industry is neither a follow-on nor a byproduct of graduate education for scientific research nor is it simply an extension of content and method of pre-professional undergraduate education. In fact, it is different because the educational aims are different, as are the professional maturity factors, experiences, and objectives of graduate engineers. As Cranch[20] 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. Because of the inexperience of undergraduates, and their stage of professional maturity, many of the professional dimensions cannot be developed until later years in graduate professional education and after the graduate has gained an established technical competency and an in-depth industrial experience base in practice.

The professional dimensions of 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.

5. SETTING A NEW DIRECTION IN ADVANCED PROFESSIONAL EDUCATION

It is now evident that most of the nation's graduate engineers enter industry or government service immediately after their baccalaureate degree preparation. After entry, most of the nation's graduate engineers pursue technology development-oriented professional career paths not centered on research.[21] They soon find themselves in professional leadership positions,[20] and they would pursue relevant high-quality advanced professional education while in industry if given the opportunity commensurate with their educational growth needs and pattern of professional learning. However, as Houle has pointed out, "… too few professionals continue to learn throughout their lives, and the opportunities provided to aid and encourage them to do so are far less abundant than they should be."[22]

5.1 Advanced Professional Education: Education for Growth Concurrent with Creative Professional Practice in Industry

Whereas, traditional graduate engineering education is focused in the context of scientific research around an intensive research thesis experience, the concept of graduate professional education for in-place graduate engineers in industry is focused in the context of needs-driven, creative professional practice around an intensive technology development thesis experience which is directly relevant to real-world needs of sponsoring industry or society. This concept builds on the long-term supportive relationship between the strengths of the experienced graduate engineer, the strengths of his or her technological organization, and the strengths of the associated universities to support the graduate professional educational process. Education is not a one-time process to be done in four, five, or eight years. Rather advanced professional education is a long-term process of continuous growth, learning, and development of human potential throughout the creative practitioner's professional career. As with other types of leadership development, this process is lifelong.

At this level of higher education, a university is without campus boundaries or limited to traditional students. There is a new clientele of nontraditional graduate students across the nation whose educational growth needs and professional experiences are quite different from that of traditional young resident graduate students who are primarily pursuing traditional academic careers in scientific research and teaching. The experienced graduate participant brings much to the educational interaction with the experienced faculty and with other experienced participants. The findings of the national graduate study[3] indicate that at the master's level over 90% of the participants in graduate education in the United States are in the professional fields outside the traditional liberal arts and sciences, and that at the doctoral level over 50% of the participants are in the professions. The findings of the national graduate study also indicate, that "… about one-half of all master's students were thirty years of age or older, and two-thirds were enrolled part-time."[3] It is now apparent that graduate education in the United States is in transformation.

5.2 Primary Decision-Situation in Graduate Professional Education for Engineers in Industry

While the conventional didactic approach to education continues to be the primary approach for traditional graduate research education, the facilitative and dialogical approaches to teaching and learning are now recognized as major attributes that contribute to the success and effectiveness of high-quality graduate professional education for practitioner-participants. The findings of the national graduate study indicate that graduate professionals, who are pursuing further graduate education, are more than just recipients in the advanced educational process, which is contrary to what conventional didactic outreach or extended distance education "transfer delivery" systems provide. Graduate professionals can be full participants in the educational process along with the professional-oriented practicing faculty, but this is dependent upon the primary decision and implementation of effective teaching, learning, and developmental approaches that foster the continued creative growth of experienced graduate professionals in this educational process for creative practice. As Hasselmo , president of the University of Minnesota and chair of the national advisory board for the graduate study, pointed out "… they are participants, along with faculty, administrators, and employers, in what is probably the most direct link between society and higher education."[3]

5.3 Facilitative, Dialogical, and Self-Directed Approaches to Advanced Professional Education

The advanced professional education of in-place graduate engineers for increasing leadership and professional responsibility of technology development is a multidimensional growth process. The approach to teaching, learning, and the development of intrinsic creative and leadership potential for experienced in-place graduate engineers can be built on three primary premises. First, that certain technical competencies can be taught and learned. Second, that the most needed relevant knowledge is learned by the practicing graduate professional through his or her self-directed inquiry when it is needed in creative professional practice and during actual technology development work. Third, that most of the professional dimensions cannot be taught. They can only be developed through actual creative performance and experiences in practice. At the advanced professional levels of engineering attainment, it is now apparent that the professional education of engineer-leaders must not only involve learning technical knowledge which is directly relevant to the technological field, which is important, but also involve the development of his or her industrial creative potential and other primary professional dimensions required for creative practice for further continuous growth in the engineering profession, which is equally important.

Accordingly, the graduate professional education of the nation's in-place graduate engineers in industry is much more than the transmission and acquisition of existing knowledge from teacher to student. The advanced educational process of in-place graduate practicing professionals requires an "integrative approach" concurrent with the graduate engineer's on-going industrial practice in engineering. The traditional didactic model of instruction and learning for postponed practice is too limited for the advanced education of creative professional engineers. It must be replaced by a higher order educational model that is more supportive of continuous individual growth, learning, and development for responsible leadership within the profession(s).

Advanced professional education is a process that goes beyond conventional didactic instruction in existing knowledge. It includes self-directed learning and inquiry as well as educational development of creative and leadership potential because creative practitioners must conceive and implement creative solutions to real-world industrial problems and societal needs that frequently go beyond conventional thinking. These solutions demand sound technical competence and the application of the intrinsic human potential of creativity, imagination, vision, judgement, responsible leadership, and original systems thinking.

As the findings of the national study indicate, "Faculty and program administrators who took a dialogical approach to teaching and learning centered their program's primary learning experiences within the context of a tacit "learning community."[3] In this setting, faculty and students participated in a variety of activities, including interactive classroom seminars, hands-on experiential learning, and informal outside-of-class conversations. In many ways, the decision to take a dialogical approach to teaching and learning was similar to the choice to adopt a facilitative approach. In both instances, faculty became involved participants in the learning process, and, in turn, students valued faculty as active contributors to their learning. And, in both instances, communication was two-way, and faculty used cooperative and experiential instructional approaches. Yet there were significant differences. Faculty who embraced a dialogical approach were less hierarchical and acted more clearly as colleagues with students. Moreover, faculty and administrators in this set of programs were committed to nurturing collaborative learning communities in which distinctions between faculty and students were not considered a precondition for effective learning. Indeed, many faculty in these programs told us that hierarchical faculty-student interactions inhibited effective learning."

6. A PLAN FOR ACTION: GRADUATE PROFESSIONAL EDUCATION FOR ENGINEERS IN INDUSTRY

The prospect is clear. Improvement of U.S. innovation and technological competitiveness is strongly influenced by improvement of the acquisition stage of technological capability. Key to improvement of this creative technological process is a nurturing industrial culture of leadership for innovation. Also important is a university culture of graduate professional education that provides the opportunity and stimulation that permits the nation's in-place graduate engineers in industry to grow. Now more than ever, America's 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.

The transformation in America's engineering education infrastructure has begun at the undergraduate level with the increased emphasis placed upon engineering design projects and multidisciplinary teams. However, the major area for transformation is at the graduate professional level — to continue the graduate professional educational growth, and career-long development of the majority of the nation's engineers, beyond entry level, who are pursuing professional careers which are aimed toward responsible professional leadership of needs-driven technology development in industry and government service. The fullest development of this vital national creative human resource for professional leadership of the nation's continual technological progress is crucial to the nation's prosperity and to ensure national security.

6.1 University-Industry Collaboration: Graduate Centers for Technology Innovation and Leadership

It is timely and of compelling national interest that universities respond to the new paradigm shift and take effective steps to reshape the graduate education of the nation's in-place graduate engineers to meet this challenge for needs-driven innovation and technology generation in industry. There is now both the conceptual clarity and the factual basis for broad national support and implementation of high-quality graduate professional education for in-place graduate engineers in industry who are the nation's critical human resource for leadership of the needs-driven innovation and technology development process.

The transformation at the nation's universities will require planned change and educational innovation to complement predominantly research-oriented cultures, curricula, and faculty with new practice-oriented graduate centers for innovative engineering and graduate professional education for leadership of technology. However, this needed educational transformation and alternative for graduate professional education for the nation's in-place graduate engineers will neither be made by the universities themselves within the constraints of today's tight university operating budgets nor made by the research-oriented faculty who are pursuing their own research-oriented career paths and interests which the current university tenure and promotion system requires.

The transformation will require a unique partnership between universities, industry, and government in order to implement this needed change and improvement in higher education. Therefore, the authors recommend that regional centers be established throughout the nation between leading universities and regional participating industry for practice-oriented graduate professional education in engineering innovation, technology leadership, and policy. As models in the nation, the centers will serve as unique "teaching and technology development" centers for engineering innovation and high-quality graduate professional education for engineers in regional industry.

6.2 Graduate Professional Education: Education for Creative Professional Practice and Leadership of Technology

The mission of the practice-oriented graduate centers will be to foster the development of engineer-leaders in industry and government service for responsible professional leadership of the nation'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 more relevant to the stages of developmental professional growth and to the dimensions of professional leadership in engineering and more conducive to the manner in which advanced practicing professionals learn, grow, and develop in professional engineering practice.

The regional centers will build on a new concept of graduate professional education, which combines advanced studies in technology leadership concurrently with the practitioner's on-going experiential growth in actual engineering practice and creative technology development work in industry. The centers will provide a very cost-effective and feasible way in which to build high-quality and innovative practice-oriented graduate professional 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. In order to meet these aims and to implement this transformation, the centers will build upon the existing strengths of the university in combination with the professional engineering strengths and technological strengths of regional industry.

One of the critical ingredients of this educational innovation is recruitment, development, and support of a strong professional faculty of distinguished, experienced engineer-leaders in industry. Combined with a solid core of resident engineering faculty and other distinguished faculty from the total university, these engineer-leaders would complement the existing graduate research-oriented academic base. These faculty would form an interdisciplinary and experienced faculty base within the center organization. The center philosophy would encourage collaborative faculty creativity in teaching and innovation across "departmental and university boundaries," between participating universities, and with sponsoring industry. Such an organizational approach has the potential to draw experienced engineers from the practicing profession, to build one of the strongest professional-oriented faculty and student bodies in the nation with industry's help and sponsorship.

6.3 Graduate Professional Education: Education Concurrent with Technology Development in Industry

As a national model, the purpose of the centers is to provide graduate engineering practitioners, in industry and government service, the opportunity and encouragement to continue their growth, learning and creative development as they assume increasing professional leadership responsibility of meaningful needs-driven creative engineering work. Because it is now recognized that leadership of needs-driven creative technology development is a unique professional practice, it is now evident that the professional education of engineer-leaders is more than simply combining traditional business courses with traditional engineering courses. The program will build on three modes of human resource development in the professions: (1) self-directed learning and inquiry; (2) professional-oriented instruction; and (3) actual creative performance in the professional practice and leadership of needs-driven innovation and creative technology development.[15]

The centers will enable experienced in-place graduate engineers in regional industry the opportunity to continue their graduate professional education and growth while employed full-time in industrial practice, and while pursing full-time technology development work. Recognizing the unique blend of technical, professional, ethical, creative, and leadership dimensions required for creative technology innovation, the initiative will set a new direction in graduate professional education for creative professional practice in innovative engineering and responsible leadership of needs-driven technology development. The program of graduate professional education is not intended to serve as a "stepping stone" along the PhD research-oriented path of graduate education, but rather as a path of excellence in its own right toward the highest leadership levels of professional engineering practice.

The focus is to provide a graduate professional education alternative that supports the process of developmental growth for the majority of the nation's graduate engineers in industry and government service. The curriculum is specifically planned and designed for experienced in-place graduate engineers who are pursuing responsible professional leadership careers centered on the creative engineering development of products, processes, systems, and operations responsive to real-world industrial and societal needs. The program's emphasis is on "doing-centered" learning, growth, and continued development of creative engineering practitioners. Accordingly, the professional-oriented curriculum will be specifically designed as a coherent matrix of advanced graduate studies which matches and supports actual assessed known educational needs of engineers in industry, the dimensions of professional engineering practice, and the nine stages of developmental growth and increasing responsibility for leadership of technology development, beyond entry level. The curriculum will combine relevant advanced studies concurrently with the practitioner's on-going creative professional practice and technology development work in industry. In this manner, the centers will directly enhance technology competitiveness and human resource development, linking creative human resource development and the generation of needs-driven technological innovation to improve U.S. industrial competitiveness.

6.4 A Learning Organization Culture: Education for Innovation and Leadership of Technology

The concept builds on the synergism between advanced professional education for technology leadership and the graduate professional's experiential growth in leadership of continuous innovation and creative technology development in industry. The overall aim is to provide an integrated practice-oriented advanced professional program to develop versatility, creativity, technical competence, and innovative leadership capabilities for the professional leadership of collaborative multidisciplinary creative engineering work to meet meaningful societal or industrial needs.

The educational culture will build on the known "characteristics of innovation best practice" using a combination of facilitative, dialogical, and self-directed inquiry approaches to teaching, learning, and developmental growth, rather than the didactic approach of traditional graduate instruction. The educational culture and overall approach to teaching and learning will be to set a new direction in graduate professional education, which further develops the capability of engineers who have an already established experience base and technical competency in industry as innovators and leaders. The concept is neither intended to provide terminal education nor to encourage graduate engineers to stop at the professional master's degree level. Neither is the program designed to be of lower quality nor require less time than preparation for a career in academic research. The concept will provide experienced graduate engineers in regional industry the opportunity, incentive, and resources to continue their advanced professional education, growth, and development for responsible professional leadership of innovation and technological development through the professional Master's level, Doctoral level, and beyond to the highest leadership levels of engineering.

Whereas traditional graduate research education is organized around an intensive research thesis experience, the practice-oriented advanced professional educational program will be organized around an intensive technology development thesis experience which is directly relevant to societal or sponsoring industry's needs. In this manner, the centers will directly enhance human resource development and the generation of needs-driven technology innovation to improve regional and national technology competitiveness. Recognizing the strength and importance of "learning-by-doing" and the significance of experiential learning in creative engineering practice, the "integrative approach" purposefully builds on the concept of advanced studies concurrent with the graduate engineer's on-going creative engineering practice in industry, as a mainstay of the program.

At this level of professional education, the participant must engage in a proactive mode rather than a passive-recipient mode of learning. Accordingly, a main aim is to provide advanced professional education of the highest quality wherein self-directed learning is a second main stay of the program. While "the contingent interaction between a tutor and a learner" is very important in certain stages of a professional's growth, the graduate engineer becomes a self-directed learner for much of his or her creative engineering work. Self-directed learning and inquiry is part of the process of actually doing needs-driven innovative engineering work. At this level of competence and professional maturity, the graduate engineer not only learns the state-of-the-art of technology in industry but also contributes to the actual generation, development, and improvement of new concepts and ideas to advance that technology. However, the graduate engineer-leader needs an educational culture which provides a learning organization and "critical mass" of encouragement and supportive educational resources that allows his or her further growth.

Recognizing that the method and approach to teaching, learning, and development of engineer-leaders is dependent upon the stage of professional growth and maturity of the individual, the program will purposefully depart from the conventional singular model of one primary approach to teaching and learning. The program will use either the facilitative approach, the dialogical approach, or the self-directed inquiry approach dependent upon the professional dimension to be developed within the individual practitioner. While the traditional focus of graduate education is on the education of individuals, a third mainstay of the program is to provide an educational culture that goes beyond independent learning and to foster a learning and innovative organization for collaborative creativity among interdependent advanced professionals, at the highest levels of collaborative learning and creative development. At this level of advanced professional education, the centers will build on the collective experience, expertise, creative talent, and wisdom of both the faculty and experienced participants in the learning and development process for collaborative growth and creativity in meaningful innovative work.

7. CONCLUSION AND NEXT STEPS TOWARD A NEW PARTNERSHIP

It is now clear that there are two distinct types of education and cultures at the graduate level and universities must serve two vital functions: (1) to be centers of excellence in scientific research to continually advance science and our understanding of natural phenomena; and, (2) to be centers of excellence in graduate professional education for innovation and leadership in the professions. These have different missions, purposes, participants, faculty, curricula, and methods. Thus, universities must stand as cathedrals of learning and human resource development, serving not only to educate future scientific researchers, but also to educate future creative leaders in the professions. Now, more than ever, 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.

Without diminishing the importance of science-driven technology, it is now understood that needs-driven technology is the primary driving force for the nation's current and future technological progress; and, that the nation's primary human resource for the generation, development and leadership of the needs-driven technology innovation process is the nation's in-place graduate engineers in industry and government service. Currently, there is no coherent educational policy for the graduate education of the nation's engineers. Their graduate education is primarily a byproduct of an educational policy which supports research because of the science-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 alternative graduate professional education programs into the nation's graduate education and technological infrastructure. There is now both the conceptual clarity and the factual basis to establish an alternative 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 and competitiveness. This transformation can be made at the nation's universities through a unique partnership between the universities, industry, and government without disruption or 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.

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