

Issues in Reshaping Innovative Professionally Oriented Graduate Education to Meet the Needs of Engineering Leaders in Industry in the 21st Century

D. A. Keating¹ T. G. Stanford¹ R. J. Bennett² R. Jacoby³ M. I. Mendelson⁴

University of South Carolina,¹ University of St. Thomas,² Cooper Union,³
Loyola Marymount University,⁴

1. Introduction and Context

1.1 Framing the Issues

As we enter the 21st century, the further education of the nation's graduate engineers in industry will become an increasingly critical component of national efforts to enhance competitiveness in the global economy. The nation's graduate engineers play a central role in the engineering leadership of continual technology innovation in industry. Continual technological innovation is recognized as the principal driving force for competitiveness and sustained economic prosperity in the global economy. Central to technology competitiveness are the primary ingredients of technical knowledge, creativity, inventiveness and engineering leadership for continual product/process improvement, and breakthrough innovation.

More than ever before, technological innovation and the supporting educational infrastructure are vital to the national interests of the United States.¹ However, while the nation is preeminent in graduate education for scientific research, it is now evident that an educational change is needed to reshape professionally oriented graduate education for engineering leadership that can significantly improve the productivity and innovative competitiveness of industry. As an outgrowth of the 1999 ASEE Annual Conference — Graduate Studies Session on Innovative Concepts in Practice-Oriented Master's Education, a steering committee was formed to address the issues that would effect this change at the national level. The steering committee has identified ten major issues associated with this change for professionally relevant graduate education for graduate engineers in industry that is in response to the 1995 National Research Council's (NRC) report by the Committee on Science, Engineering, and Public Policy. That report, "Reshaping the Graduate Education of Scientists and Engineers," calls for a broader, more flexible graduate education system to support national goals for science and technology.² The required change represents a divergent education for professionally oriented graduate engineers in industry that emphasizes creative engineering and engineering leadership, as opposed to the convergent education that focuses on research for scientists.

1.2 Reshaping Graduate Education for Engineers in Industry

The need to reshape professionally oriented graduate education to further develop engineering leaders and technology in industry is now evident by the nation's necessity to improve its competitiveness in the technology-based economy. As the 1995 NRC report stated:

"... Scientists and engineers with PhD and other advanced degrees play a central and growing role in American industrial and commercial life. The traditional process of graduate education to the doctoral level, organized around an intensive research experience, has served as a world model for the advanced training of scientists and engineers.

... Graduate education is basic to the achievement of national goals in two ways. First, our universities are responsible for producing the teachers and researchers of the future — the independent investigators who will lay the groundwork for the paradigms and products of tomorrow and who will educate later generations of teachers and researchers. Second, graduate education contributes directly to the broader national goals of technological, economic, and cultural development. We increasingly depend on people with advanced scientific and technological knowledge in our collective efforts in developing new technologies and industries ... and maintaining the competitiveness of industry. Our graduate schools of science and engineering are therefore important not only as sources of future leaders in science and engineering, but also as an indispensable underpinning of national strengths and prosperity — sustaining the creativity and intellectual vigor needed to address a growing range of social and economic concerns."²

1.3 Funding of U.S. Graduate Education for Research

As the 1995 NRC report noted:

“ ... The American system of graduate education of scientists and engineers, organized around an intensive and realistic research experience, has become the world model for simultaneously conducting basic research and educating graduate scientists and engineers.

The efficacy of our system originated in a series of policy decisions that were prompted by the major role that science and technology had in the outcome of World War II. Among those decisions were the following:

- The public, through a number of government agencies, would assume an important role in funding basic and applied research.
- Through public funding, researchers at universities throughout the country would become major contributors to the nation’s scientific research expertise.
- The universities would conduct basic research and the graduate education of scientists and engineers as joint, synergistic activities.
- The dual role of the graduate science and engineering enterprise was designed to benefit the nation by educating students through the active conduct of cutting-edge research. According to a report by the National Research Council in 1964, “graduate education can be of highest quality only if it is conducted as part of the research process itself” (NRC, 1964). By educating students in the context of research, the American system of graduate education has set the world standard for preparing scientists and engineers for research careers in academe, government, and industry.”²

1.4 Changing the Context of U.S. Graduate Education for Engineers

Although the U.S. system of graduate education for research has proven to be a world leader, “and is one of the nation’s strengths in carrying out graduate education where a large portion of the nation’s best research is done”, it is now evident that a change is required.² The change that is required is not a change in the graduate education of the nation’s scientists and engineers for academic research. Rather it is a change in the advanced professional education of the nation’s engineers in industry who are pursuing non-research professional careers for creative engineering leadership of needs-driven continual technological innovation in industry.

As the 1995 NRC report noted:

“ ...Although many recent graduates are frustrated by their inability to find basic-research positions, it appears that the growth in non-research and applied research and development positions is large enough to absorb most graduates.

... A broader concern is that we have not, as a nation, paid adequate attention to the function of the graduate schools in meeting the country’s varied needs for scientists and engineers. **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. 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.

... If scientists and engineers are to contribute effectively to national, scientific, and technological objectives, **their educational experience must prepare them to do so** ... American graduate schools have done a superb job of preparing young scientists and engineers to become original researchers ... Graduate scientists and engineers have traditionally been educated for employment positions in which the ability to perform original research is the skill of highest value. The traditional positions include research-intensive occupations in academe, industry, and government laboratories where scholarship and research — constitute the primary focus of employment.

... The process of graduate education is highly effective in preparing students whose careers will focus on academic research. It must continue this excellence to maintain the strength of our national science and technology enterprise. Nevertheless, the committee believes that there is room for substantial improvement in graduate education and that some immediate changes are needed ... **Graduate education must also serve better the needs of those whose careers will not center on research** ... It is time for a fuller recognition, by academics and policy officials alike, of the changing ways that graduate education in science and engineering contributes to the wide array of national needs. For many of these needs, it is a career in professional service ... More than half of new graduates with PhDs now find work in nonacademic settings. This fraction has been growing for two decades ...”²

2. The Conceptual Framework for High Quality Graduate Education Which Develops Engineering Leaders in Industry

2.1 Meeting the Nation's Goals for Academic Research and for Creative Engineering Leadership of Needs-Driven Technological Innovation in Industry

As the 1995 NRC report pointed out, although graduate schools have typically seen their missions as producing the next generation of academic researchers through immersion of young resident students in an intensive research experience, most graduate engineers in industry are pursuing professional careers that do not center on research. Engineers with advanced degrees play a central and growing role in American industrial and commercial life. They contribute directly to national technological goals for economic development and for national security.

To meet the needs of these professionals, graduate schools need to review their mission and expand their important role in society. Sustained U.S. technological progress is directly linked with the nation's policy for graduate education of its creative professional engineers. The lack of a coherent national policy to support the advanced professional education of the nation's engineering leaders in industry has hindered U.S. competitiveness. The U.S. civilian technology policy and its supporting graduate education system were initially devised in 1945. This policy was based upon a linear research-driven model of technology innovation, wherein academic research would be generated at the nation's top research universities through public funding and the results would be transferred for exploitation and commercialization in industry. After four decades, however, it is recognized worldwide that the linear research-driven model doesn't fit the needs-driven technological innovation process.^{3,4,5} Nor does the linear research-driven model of educating engineers at the graduate level — to be either basic scientific researchers or strategic researchers — fit what most creative engineering leaders do in industry.

2.2 Developing New Models of Graduate Education for Creative Engineering Innovation and Leadership in Industry

The nation's graduate engineers in industry play a more important role in the technological innovation process than previously thought. It is now recognized that the further development of the U.S. engineering base in industry is essential to meeting America's technology goals in the future. Successful technological innovation is fostered by successful engineering leadership in industry and the further development of creative engineering talent in industry.

Today, graduate education is undergoing global change. New paradigms are being developed to improve national technological competitiveness in developing and in developed nations for economic growth.⁶ Human resource schemes to link technological innovation in industry with the professional development of graduate engineers are being implemented worldwide. However, to be successful personnel-based schemes must be based upon an understanding of the continual technological innovation process and that science and creative engineering innovation are two different nonlinear activities, with different aims, missions, talents, and methods.

2.3 Defining the Needs-Driven Engineering Innovation Model of Graduate Education for Continual Improvement and Breakthrough Technological Innovation in Industry

As the Basic Research White Paper noted, research plays a different role in the nation's creative technology development and innovation process than the linear research model portrays.⁵ Whereas the linear research-driven model of technology innovation assumes stepwise progression from scientific discovery to technology development, it is now known that research plays more of an integrative and supportive role in the overall technological innovation process.

While curiosity-driven basic research is primarily the realm of academic researchers at research universities and is performed to gain a better understanding of phenomena or scientific principles, successful engineering leadership of needs-driven technological innovation is primarily the responsibility of creative engineering leaders in industry. Yet the nation's graduate engineers in industry are one of the nation's most underdeveloped resources due to the pervasive belief in the linear research-driven model of technological innovation.

Support for the linear research-driven model as the presumed source of technology innovation in the nation is found among most faculty at research universities. Consequently, these same research universities have not supported innovative professionally oriented graduate education through the master's level, doctoral level, and beyond, for creative engineering practice and responsible engineering leadership of needs-driven continual technological innovation in industry.

Confusion about the roles of academic research and creative engineering innovation has existed for over three decades in academe because of the widespread acceptance of the linear research-driven model. However, the linear research-driven model has proven to be an ineffective, incorrect, and outmoded means for continual technological innovation and competitiveness in the global economy. The linear research-driven model is now recognized worldwide to be in error. Technological innovation is a complex, needs-driven continual process. As Mary Good, former Undersecretary for Technology in the U.S. Department of Commerce, stated: “... The linear model is wrong ... Policy based on it is destined to fail because it’s not reality.”⁵

2.4 Integrating Creative Engineering Innovation and Strategic Research to Enhance Economic Growth and to Increase U.S. Competitiveness

Although basic research is vital to the nation’s scientific progress, it is not the first step in the creative engineering process for needs-driven continual technological innovation in industry. Much of U.S. industry’s improved competitiveness in civilian technology during recent decades has been due to “the press of foreign competition that drove significant changes in industry.”⁷ Continual technological innovation is conducted primarily in industry and in mission oriented government agencies as a systematic needs-driven concurrent process and practice which requires creative engineering leadership.

Needs-driven creative engineering innovation is not a follow-on to academic research. Neither is creative technological development the translation of academic research findings for commercialization in industry. Creative engineering innovation has evolved as one of the nation’s greatest strengths. However, its use is neither as wide spread nor as understood as it should be. In this process, graduate engineers use scientific knowledge, technical knowledge, their intrinsic creative potential, and their engineering judgment, ethics, values, and professional leadership skills to bring about effective creative solutions to meet previously unmet real-world needs.

Today, continual needs-driven technological innovation is a systematic practice of creative engineering that is the result of two primary pursuits: a) the deliberate exploitation of the results of curiosity-driven basic research and discovery, and; b) the deliberate use of the needs-driven creative engineering method to purposefully create, invent, develop, and innovate new and improved technology.⁸ Today, continual technological innovation in industry is primarily the result of, and the deliberate use of, the purposeful systematic needs-driven method of creative engineering development and innovation. The lion’s share of new and improved technological innovation results from the deliberate use of the systematic needs-driven creative engineering development method — from exploratory engineering development and proof of feasibility and concept, through advanced engineering development and systems engineering development for operational use. In both wartime and peacetime, the pace of technology innovation is accelerated by real needs and by the use of the creative engineering development method to provide creative solutions and new technology to meet those needs.⁸

Although academic research and strategic research serve vital functions in scientific progress, they are different functions from that of technological innovation. However, strategic research serves a different purpose than does basic academic research. Strategic research is often technology project-driven rather than curiosity-driven. Its purpose is also to gain a better understanding of phenomena when new knowledge is needed to solve fundamental scientific problems related to products, processes, systems, and operations. As Cauffman, chief scientist at the Department of Energy’s Idaho National Engineering and Environmental Laboratory, stated: “... A lot of the fundamental work today is driven by a need ... but it is still an effort to understand the fundamental way things interact.”⁵

2.5 Recognizing that Graduate Engineers in Industry are Responsible for Leadership of Continual Technology Innovation and Economic Prosperity

As Morita, former chairman of Sony Corporation, expressed in 1992 at the First UK Innovation Lecture: “...Science does not equal Technology ... and ... Technology does not equal Innovation ... It is engineers, not scientists, who make technology happen. ... the true visionaries who can really capture technology and use it to chart the future course of industry ... who have a wide understanding of science and engineering, as well as a broad vision and true commitment to the needs of society. People with this depth of understanding can adapt and apply technology with imagination, wisdom and humanity.

... I believe we should not only encourage more young people to pursue engineering studies, but we must also — on the corporate level — advance young engineers through the leadership ranks ... high technology corporations must be led by those who understand not just business but technology as well.

... While certainly it is good and noble to place emphasis on basic research and science, placing too many eggs in this basket takes away from the important work done by commercial engineers ... This imbalance is not only a financial one, it is also a question of prestige; the image society has of engineers versus scientists.

... Thus, in order to succeed in maintaining and strengthening the vital industrial base of the economy, it is crucial that society helps to encourage the development of more engineers ... Now if we can agree that science alone is not technology, and it is technology which drives industry, and it is the engineer who guides technology, we must also agree that the role of the engineer deserves more respect from society and a higher priority by industry.

... Industry must encourage and advance the engineers within its own ranks ... By placing greater value on engineers, we demonstrate our commitment to place greater value on high and new technologies ... The innovation process begins with a mandate which must be set at the highest levels of the corporation ... The innovation mandate can only succeed in an environment which nurtures it ... Creating this environment is not an easy task, but without it innovation does not have much of a chance ... but ... once it starts rolling it is very hard to stop ... ”⁹

3. High Quality Professionally Oriented Graduate Education to Develop Engineering Leaders and Technology in Industry Simultaneously

3.1 Stimulating Economic Growth Through Engineering Innovation and Leadership in Industry

The conceptual framework for the new model of advanced professional education to improve the competitiveness of U.S. industry must address the new evolving model of the technological innovation process. Although there is substantial room for improvement in research-oriented graduate education, the conceptual basis to reshape graduate education for the nation's engineering leaders should be based neither upon the inability of recent PhD academic researchers to find jobs in universities nor their lack of versatility to tackle nonacademic problems, although that is an issue for industrial research. Rather the conceptual basis for this needed change in the further graduate education of the nation's engineers is based upon a new and better understanding of the technological innovation process itself.

The importance of reshaping U.S. graduate education to meet the relevant professional growth needs of graduate engineering leaders in industry is nationally and internationally significant. Measures are being taken worldwide to better develop engineering resources at the graduate level. Setting a new direction for alternative professionally oriented graduate education will improve America's technological infrastructure and her industrial base to enhance U.S. competitiveness.

Both the conceptual and factual basis to make this educational reform are now clear and the resources are at hand to effect this improvement in graduate education in the United States. At innovative universities across the nation there are movements toward a balance between graduate education for academic research and graduate education for meaningful creative service in the professions. This will require new program development directed at increased breadth, flexibility, and versatility in order for advanced professionals to continue to tackle new real world problems and unmet human needs. Response to the challenges of lifelong education in the professions will require that research universities set new integrative directions in professional education and to enter into multi-university collaboration in new model development for institutionalization of high quality professional education into university operations.

3.2 Designing Graduate Education for Engineering Innovation and Leadership in Industry to Complement Graduate Education for Academic Research at Universities

There are several integrative directions that are needed to effect new model development and to institutionalize this change at universities in partnership with industry. These directions are based upon the known attributes of high-quality graduate education as determined from the 1993 national study by the Council of Graduate Schools; assessment of the known stages of growth within the practicing creative engineering profession, and assessment of the dimensions of responsible engineering leadership of technological innovation in industry.^{10,11} The recommendations for change are summarized as follows:

Recommendation 1: New Model Development and Vision for Market Assessment of the Continuing Wave of Professional - Oriented Part Time Graduate Students in Industry.

The first direction for new model development must address the size and sustainability of the market need for this type of professionally oriented graduate education for engineering leaders in industry. Most American graduate engineers enter the engineering profession in industry or government service immediately upon completion of their pre-service undergraduate engineering education and only a relative few remain at the universities to pursue research-oriented graduate education for scientific work.² Those graduate engineers who enter industry represent an

underdeveloped constituency of professional-oriented part time students in industry that is a growing graduate professional educational market which has largely gone unnoticed and has taken “second class” status at research universities.

However, as determined from the 1993 national study by the Council of Graduate Schools:

“...despite often being relegated to second-class status within academe, master’s education is far more successful than the literature and the conventional wisdom suggest, and it provides a critically important bridge between colleges and universities and the professional workplace.

... Of the people earning master’s degrees since the early 1980s, about 90 percent earned degrees in professional fields outside the traditional liberal arts and sciences ... About **one-half of all master’s students were thirty years of age or older**, and **two-thirds were enrolled part-time**. For the most part, this is not the population that graduate education in the United States has served historically. Yet it is increasingly the population upon which business, industry, education, government, and our health care systems depend for expertise and leadership.”¹⁰

Recommendation 2: New Model Development and Vision to Support the Mission and Purpose of the Creative Engineering Profession in Industry.

The second direction for new model development reflects upon the need to address the specific aims of professionally oriented graduate education to support the mission and purpose of the engineering profession in industry and to support what engineering leaders are responsible for doing in creative professional practice. Most of the nation’s graduate engineers are pursuing non-research oriented professional careers in industry or government service aimed toward improving, creating, developing, and innovating technology to meet the needs of society. These graduate engineers assume responsible roles in the engineering leadership of continual needs-driven technology generation, development, and innovation in industry. They represent the nation’s industrial strength for responsible engineering leadership of the continual technological process for future national security and for further progress of sustained economic development across the nation.

Whereas the American system of graduate education of scientists, conducted in the context of scientific research and discovery and organized around an intensive and realistic research experience, has become the world model for simultaneously conducting academic research and educating graduate scientists, the reform for innovative professionally oriented graduate education calls for an alternative model of graduate education, conducted in the context of creative engineering innovation and organized around an intensive and realistic creative technological innovation experience in industry. This new educational reform would require an integrative approach between concurrent professionally oriented graduate studies and creative engineering practice in industry as joint synergistic activities.

Recommendation 3: New Model Development and Vision to Support Professionally Oriented Graduate Studies for Engineering Innovation, Responsible Leadership and Lifelong Growth in Creative Professional Service

The third direction for new model development reflects upon the need to develop innovative professionally oriented graduate education that supports the furthering of increased professional maturity, competency, growth, and progressive responsibilities of engineering leaders, beyond pre-service undergraduate engineering education.

There are nine progressive levels of increased competency, professional responsibility, autonomy, and leadership beyond completion of the young graduate’s pre-service undergraduate engineering education. Whereas pre-service undergraduate engineering education prepares the young graduate engineer for entry level, the objectives of professional education aim at the higher dimensions of engineering leadership. These dimensions include the development of increased technical competency in the engineer’s field of technology, the further development of creative and innovative engineering skills, the further development of ethical and professional responsibility, the development of engineering leadership through program making and technology policy making levels of executive leadership.

The stages of growth, characteristics, responsibilities, and the professional dimensions of creative engineering leadership that extend beyond entry level are well known.¹¹ Pre-service undergraduate engineering education prepares the young graduate engineer at entry level for professional work. Growth to the higher levels of creative professional engineering is dependent upon further experience and further post-graduate advanced professional education. Many of the professional dimensions cannot be developed in undergraduate engineering education because of the maturity level and inexperience of the undergraduate student.¹² Many of the higher dimensions of creative professional practice can only be developed through actual progressive engineering leadership experience in practice and through post-graduate advanced professional studies. The primary focus of the reform would be on fostering lifelong learning, growth, and development for each participant to reach his or her fullest creative, innovative, and leadership potential in the practice of creative engineering. The advanced studies program should

extend through the highest levels of professional engineering leadership for lifelong growth through the professional Master's level, Doctoral level, Fellow level, and beyond.

The emphasis of this educational reform would be to provide progressive high-quality professionally oriented graduate education for in-place graduate engineers in industry — from the young graduate level through the experienced executive engineering leadership levels — to further the growth of the creative professional engineer who is assuming increasingly responsible leadership roles in the creative practicing profession. The professional oriented curriculum would be specifically designed to match the stages of growth, engineering responsibilities, and the progressive professional dimensions of engineering leadership — which is a unique professional creative practice. A key objective would be to encourage creativity, innovation, and leadership in engineering.

Recommendation 4: New Model Development and Vision to Support an Innovative, Professionally Oriented Graduate Curriculum that Combines Concurrent Graduate Studies, Progressive Professional Engineering Experience, with Creative Engineering Practice in Industry as Joint Synergistic Activities

The fourth direction for new model development reflects upon the need for a new approach in professional education which recognizes the joint synergistic effects of combining concurrent industrially relevant graduate studies, progressive engineering leadership experience, with on-going creative engineering practice in the context of continual technological development and innovation in industry.

The professionally oriented graduate curriculum would be specifically developed to combine core professional course work, technical electives specifically relevant to the participant's field of technology, progressive engineering experience, and immersion in a substantive technology innovation project-thesis experience directly relevant and significant to the real-world needs of the participant's sponsoring industry. This reform would provide a mechanism for "doing-centered learning", growth, and continuous professional development to enhance creative engineering leadership and innovation in industry. This requires a professionally oriented curriculum of innovative graduate studies specifically designed to permit full-time employment in industry; to be concurrent with the engineering leader's creative engineering practice in industry, and; to be conducive to the manner in which advanced engineers continue to learn, grow, and develop in needs-driven creative technological innovation in industry.

To provide for evolutionary improvement, the program of professionally oriented graduate studies would be renewed on a dynamic basis, ensuring that it is directly relevant to the progressive growth needs of the participating engineering leaders in regional industry. The intent of this reform is to offer courses that meet the engineering leader's professional growth needs. In this manner, the participants, industry, and the regional university would continually grow together. The curriculum of professionally oriented graduate studies would include both the theoretical work and the practical engineering work necessary to enhance the participant's field of needs-driven creative technological innovation. This high quality professionally oriented graduate studies program would be initially designed, implemented, and continually improved at universities in strong partnership with regional industry to protect and to nurture this professionally oriented direction as an alternative to the traditional research-oriented program of graduate education.

Recommendation 5: New Model Development and Vision to Support a Process-Centered Model of Professionally Oriented Graduate Education that is Conducive to Engineering Innovation and Leadership of Needs-Driven Continual Technological Innovation in Industry

The fifth direction for new model development reflects upon the need for a new approach in professional education that supports the process by which graduate engineers in industry continue to learn, grow, and develop in the responsible engineering leadership of needs-driven continual technological innovation in industry.

Academic research at research universities and creative engineering innovation in industry have unique educational requirements which mandate that the approach to innovative professionally oriented graduate education for experienced engineering leaders in industry be different from that of the traditional approach to research-oriented graduate education for future academic researchers and from that of pre-service undergraduate engineering education for entry level inexperienced students.

Whereas the traditional approach to graduate education at research universities is based primarily upon a research-driven model of instruction emphasizing the "transmission and acquisition of knowledge" from teacher to student and inquiry-based learning for scientific investigation, professional graduate education for creative engineering seeks a different aim and requires an innovation-driven process model of professional education to develop both the advanced skills of creative engineering practice and the higher dimensions of engineering leadership to foster the creative, innovative, and leadership growth of the experienced engineering leader in industry.

As pointed out in the 1993 national study by the Council of Graduate Schools, decisions about the approach to teaching and learning must be reflective of the orientation, culture, and aims that any specific graduate education program intends to effect. Such is the case with this new program of innovative professionally oriented graduate

education which would support the continual growth of experienced creative engineering leaders in industry. The new model development would be based upon the underlying premise that the systematic creative engineering practice of continual technological innovation itself requires, in addition to didactic learning, not only self-directed learning and collaborative creative learning but also an innovative culture, and the development of intrinsic creative, innovative, and leadership potential. The new model development would be based on lifelong learning experiences since the development of engineering leadership, as with any leadership development, is a process of lifelong growth and development of intrinsic human potential.¹³

The program of innovative professionally oriented graduate studies would be specifically designed to match five modes of professional learning and development to effect increasing professional growth, creativity, innovation, and professional responsibility in engineering leadership. These modes would include: a) self-directed professional learning; b) collaborative creative professional learning; c) advanced professional oriented education using dialogical and facilitative methods; d) experiential based-learning, and; e) creative professional performance in the engineering leadership of needs-driven continual technological innovation in industry. This approach would require use of actual on-site learning in industry, distance learning, internet learning, seminars, self-study, course modules, case studies, residential collaborative learning and collaboration, and substantive creative engineering project work. Although leadership development of experienced engineering leaders is primarily the development of individual human potential, it is also the development of collaborative creative human potential. As Kouzes and Posner have pointed out: "... Hundreds of executives have told us that one of the main reasons they attend the executive seminars we conduct at our university is to interact with the other executives in the room..."¹⁴

Recommendation 6: New Model Development and Vision to Support a Substantive Thesis-Project for Needs-Driven Creative Technological Innovation to Meet Real-World Industrial Problems and Society Needs

The sixth direction for new model development reflects upon the need for a new approach to professional oriented graduate education that supports the highest leadership aims of the creative profession of engineering "to meet the needs of society ... for the advancement and betterment of human welfare."

The professionally oriented program of graduate studies would build upon a substantive thesis-technology innovation project as a mainstay of the overall program and as an intensive, integrative experience. Whereas traditional research-oriented graduate education is centered around an intensive research experience, new model development of professionally oriented graduate education for engineering would be centered around a real-world needs-driven creative technology innovation experience, conducive to the mission and purpose of the creative profession — either for economic development or for improvement in the quality of life. This creative engineering thesis-project would be valued and significantly relevant to the real-world needs of the engineering leader's sponsoring industry. It would be jointly guided by industry and the university's core program faculty. University graduate faculty would be deeply involved in needs-driven creative technological innovation in industry, thereby strengthening not only the teaching efforts of the faculty but also the ties of the university with sponsoring regional industry. The needs-driven creative project-thesis would be the primary integrative center for the participant's creative, innovative, and leadership professional educational experience to be valued both by industry, the university, and the participant engineering leader.

Recommendation 7: New Model Development and Vision to Organize and Support a Combined University-Industry Faculty with Professional Work Experience in Meaningful Technological Development and Innovation

The seventh direction for new model development reflects upon the need to organize innovative professionally oriented graduate education for engineering leaders in industry around the strengths of a university-industry faculty who have work experience in real-world needs-driven creative technological development and engineering innovation.

Because of the emphasis during the last three decades upon the linear research-driven model of technology innovation, most faculty at research universities have very little background or experience in creative engineering innovation in industry or government service. A major criticism of American engineering education has been the inexperience of research-oriented university faculty in matters that deal with real world creative engineering development, innovation, and responsible engineering leadership. While, the ability of faculty at research universities to conduct academic research is second to none "teaching research isn't teaching engineering."¹⁵

For the U.S. to strengthen and to sustain professionally oriented graduate education for the nation's engineering leadership base in industry it must build and sustain its professional faculty strength in professional engineering education. Toward this operating goal, new model development for professionally oriented programs would build around a core of professionally oriented engineering faculty, distinguished university faculty drawn from the total university system, and experienced distinguished adjunct faculty from regional and national industry. As pointed out in the 1993 national study by the Council of Graduate Schools, faculty with professional non-university workplace experience often contribute important insights and understandings that enhance professional learning. Very

effective programs have been effected across the nation by employing part-time adjunct professors who worked full-time as professionals in the non-university workplace.¹⁰ This formidable strength would work with a creative practicing professional part-time student body of emerging, experienced, and innovative engineering leaders in industry who will be responsible for the state's and the nation's future creative growth in competitive technological innovation.

This unique approach would provide research universities a very cost-effective organizational approach to develop an experienced professionally oriented core faculty base supported by an experienced industrial adjunct faculty. This would provide smaller universities not centered on research the opportunity and resources to achieve first tier status as high-quality professional institutions when they might not have had the desire, the opportunity, or the funding to achieve such status in academic research.

Recommendation 8: New Model Development and Vision to Support Institutionalization of Professionally Oriented Graduate Education in University Operations to Complement Graduate Academic Research

The eighth direction for new model development reflects upon the need to develop strong institutional support of professional education at both larger research universities and at smaller universities. Whereas large research universities are often ranked according to the amount of federal research money that they attract, and because young research faculty are told they will be promoted and tenured on this basis, the institutionalization of high quality professionally oriented graduate education probably will not receive the first rate support that it deserves.¹⁶

There is little doubt that the federally funded linear research-driven model of technology innovation has become pervasive and will continue to be so. However, universities are now revising their overall missions to include professional education. Professionally oriented graduate education will provide a substantive mechanism for university growth, increased enrollment, and increased tuition revenue, and will strengthen relationships with regional constituencies of legislative bodies and industry. Professionally oriented graduate programs represent a very favorable complement to the university's academic research function.

As the 1995 NRC report, "Reshaping the Graduate Education of Scientists and Engineers", pointed out, there is substantial room for improvement of graduate education through the Ph.D. level, and beyond, for those professionals who are pursuing non-research oriented professional careers in creative professional service. These engineering leaders who represent the technological strength of the nation also represent a neglected yet substantial educational market for part-time graduate student tuition and an avenue for increased funding support by industry in university-industry strategic research activities. These benefits must be made known to university administrations and to government economic development bodies without whose support the reform for professionally oriented graduate education in most universities is doomed or hindered.

Because of the emphasis at most universities on research-oriented graduate education, on research-oriented curricula, and on research faculty, it is unrealistic to assume that this educational innovation fits into the existing departmental structure. The professional program will require its own unique culture which supports innovation and its own unique organizational structure which recognizes creativity. As the 1993 national study by the Council of Graduate Schools pointed out, "In those cases in which a master's program was not located within a departmental structure, the administrative unit supporting the program usually was a school, college, center, or institute."¹⁰

Recommendation 9: New Model Development and Vision to Support Continuity of Funding for Professionally Oriented Graduate Education through University-Industry-Government Partnerships

The ninth direction for new model development reflects upon the need to develop new approaches to support continuity of funding for initial developmental start-ups and for continuous innovative improvements of professionally oriented graduate education for engineers in industry through unique university-industry-government partnerships for economic development.

The effectiveness of initiating this reform across the nation would be dependent upon the commitment of the stakeholder partnership between industry, universities, and government that is prompted by the national interest and the national importance of enhancing the U.S. economy and national security by stimulating continual technological innovation in industry for increased competitiveness through the advanced professional education of the nation's engineering leaders in industry.

The national impact, through this educational reform to stimulate enhanced technological development and innovation in industry, can bring significant economic growth across the nation. While there is no doubt about the importance of promoting federally funded academic research at the nation's research universities, the national importance of promoting technological development and innovation in industry cannot be discounted. Although funding for the nation's academic researchers has been established and has been in place for over three decades, there is no coherent policy nor is there a coherent funding scheme, for the advanced education of the nation's

engineering leaders, who are pursuing non-research oriented professional careers in the engineering leadership of technological development and innovation

Because of tight operating budgets and the competition for funds that exists at most universities, it is unrealistic to assume that the establishment of professionally oriented graduate education will simply occur across the nation because either it is a good idea or because there is a real need for this to happen. Although the public, through the federally funded linear research-driven model of technology innovation, has assumed the primary role in funding academic research and in educating future academic researchers at the nation's research universities, different funding models are needed to sustain the development of professionally oriented graduate education for the nation's engineers in industry.

Industry and state government, through state initiatives for economic development, must assume a primary role in the funding of this educational reform. Through existing tuition reimbursement policies, industry now offers significant support for advanced education of its engineering leaders. Industry could also help to identify and to provide distinguished professionally oriented adjunct faculty to complement existing university faculty expertise. State economic development bodies, in partnership with industry and university benefactors, could provide continuity of funding for developmental start-up and for continual innovative program improvement. Universities would provide funding for infrastructure and for necessary overhead expenses. The precedent for federal government support, if needed, has also been set to support both the development of the nation's scientific research infrastructure and the development of the nation's engineering infrastructure for economic growth. As the National Goals for Science and Technology indicate: "Over the long-term national interest calls for investment in the human and intellectual capital that are essential, ultimately, to the development of technological innovation in the modern world."¹⁷ But industry and state government must share the bulk of the investment in the professional education of engineering leaders in order to attract industry and to sustain the growth of industry in their industrialized regions of the nation.

Recommendation 10: New Model Development and Vision to Support the Development of Technology Innovation in Industry and the Development of Engineering Leaders in Industry Simultaneously as Joint Synergistic Activities to Enhance U.S. Competitiveness for Economic Development Across the Nation

The tenth direction for new model development reflects upon the need for a collaborative university mechanism to innovate the reform as a national demonstration pilot project in developing technology innovation in industry and for developing engineering leaders in industry simultaneously as joint synergistic activities.

The innovation of the pilot project in various regions of the nation would bring collaborative universities and industry closer together as demonstration models for "best practice" to continually stimulate needs-driven technological innovation and to develop the nation's engineering manpower base. Providing professionally oriented education to engineering leaders in industry, within the context of continual technological innovation, will have great economic benefits across the nation. This will support industrial creativity and engineering innovation throughout all levels of the engineering profession in industry — from the beginning graduate engineer through the executive engineering leadership levels for responsible corporate technology innovation, policy, and strategy. It is expected that market-driven technological innovation resulting from this educational reform will outweigh the modest investment in professional education of the nation's creative engineering leaders.

Focusing professionally oriented graduate education in the context of continual needs-driven technological innovation will develop an industrial culture for technological innovation throughout the nation and it will also provide industry with tangible new innovative technology which can be used for competitive advantage in the global economy. The impact of this initiative is substantial. Innovative universities with high-quality professionally oriented graduate programs across the nation should be able to attract a minimum of 50 to 100 engineering leader-professional students per year from participating regional industry. This would represent the stimulation of 50 to 100 technological innovation projects relevant to industry's needed innovative technological thrust. If the envisioned pilot demonstration program starts in five regions, this would result in 250 to 500 technological innovation projects, each initiated by and important to industry. If all 50 states were brought to the task, this would represent a formidable increase in national technological competitiveness of 2,500 to 5,000 new technological development and innovation project efforts at minimal government investment. This modest investment to unlock the innovative potential of the nation's creative graduate engineers in industry through innovative professionally oriented graduate education has significant returns for the nation's future and for sustained economic growth and prosperity in the competitive world economy.

5. Major Issues to be Negotiated in Building Professionally Oriented Graduate Education To Meet the Needs of Engineering Leaders in Industry

The need to reshape professionally oriented graduate education for engineers in industry has been voiced by the practicing profession in industry, worldwide. However, there are several major issues that must be addressed in order for universities to effect this needed educational transformation. They are:

Issue 1: Why implement a program of post-graduate professionally oriented education for engineering leaders in industry?

Issue 2: Who benefits from professionally oriented post-graduate education for engineering leaders in industry?

Issue 3: What is the synergy between innovative professionally oriented post-graduate education for engineering leaders in industry and university strategic research for industry?

Issue 4: What are the national, industrial, and university returns of innovative professionally oriented post-graduate education for engineering leaders?

Issue 5: What are the stages of growth and the dimensions of engineering leadership which must be developed after pre-service undergraduate engineering education to foster engineering leadership of continual technology innovation in industry?

Issue 6: What is the professional curriculum which matches the stages of growth and dimensions of engineering leadership for lifelong growth through M.Eng., D.Eng., and Fellow levels of creative engineering leadership in industry?

Issue 7: What educational methods can be used to concurrently integrate relevant professionally oriented post-graduate education with the engineering leader's on-going creative practice in industry?

Issue 8: What is the quality level, experience level, and mix of faculty from the university and industry that is required for innovative professionally oriented post-graduate programs?

Issue 9: How can an alliance between universities, industry, and government be created to achieve continuity of funding for start-up, for development, and for continual program improvement and sustainability?

Issue 10: How can an organizational infrastructure for this educational innovation be established within research universities to overcome initial academic resistance and to provide continual educational leadership and direction for high-quality innovative professionally oriented post-graduate education?

While we recognize that those who implement these programs must address unique issues separate from those presented here, we present these only as a means to open a dialogue to establish a commonality among program developers.

5. Conclusions and Next Steps

5.1 Main Conclusions of the Paper

There are five main conclusions that emerge from the concepts developed in this paper:

■ **Worldwide, nations are taking steps to ensure economic prosperity through technology innovation**

In order to prosper in the 21st century, the United States must continue to be a world leader in technological innovation in industry. Strategies for competitiveness are on the rise worldwide. Measures are being taken by nations around the world to promote technological competitiveness and to attract, create, grow and retain world class technology-based industry for economic growth.

■ **Science and technology are two different components of the complex system that ensures progress**

In promoting strategies to enhance National Goals for Science and Technology in the United States, one critical element is the recognition that Scientific Research and Technological Development are two **different nonlinear** components of a complex system which supports the nation's scientific progress and the nation's technological progress. The primary source of the nation's scientific progress is its scientific base in research universities. The

primary source of the nation's technological progress is its creative and innovative engineering leadership base in industry. Both science and engineering are necessary for the nation's long-term economic prosperity.

■ **The nation needs both academic research and technological development to ensure economic growth**

The fullest development of the nation's human resources both in scientific research and in creative engineering for technological development and innovation is essential to meeting the fundamental challenges in the nation's science and technology enterprise. There is a difference between academic scientific research that is performed in universities and creative engineering that is performed in industry. Academic scientific research is primarily performed in universities by research-oriented faculty and graduate research students. It is a process of scientific inquiry conducted in order to gain a better understanding of phenomena; technological development and innovation is primarily performed by graduate engineers in industry. It is a process of needs-driven systematic creative engineering conducted in order to deliberately and continually improve, develop, and innovate new products, processes, systems, and operations. Society needs both of these pursuits.

■ **People are the most important component of the RTDI enterprise**

It is now recognized worldwide that people are the most important component of any nation's Research, Technological Development and Innovation (RTDI) enterprise. Graduate scientists at research universities and graduate engineers in industry contribute to the science and technology enterprise. Whereas the educational development of graduate research scientists at the nation's universities has been in place for over three decades, the educational development of the nation's graduate engineers in industry needs to be implemented across the United States. This paradigm shift in professional education for the nation's engineers is necessary in order to ensure the nation's continual technological development and innovation thrust for competitiveness in the global economy. Countries are now recognizing that personnel-based schemes are of critical importance, and that they should be the primary goals of policy-makers who wish to implement indirect strategies that have maximum impact on employment in the RTDI enterprise.¹⁸

■ **The nation must implement a high-quality personnel-based scheme of professional education for engineers**

It is timely to implement high quality personnel-based schemes of professionally oriented graduate education across the United States to further develop the nation's in-place engineers as innovators and leaders of the continual technological innovation process in industry. Personnel-based schemes to further develop in-place graduate engineers as leaders and innovators of technology are now being linked directly to the simultaneous development of technology in industry as a synergistic activity. On a global basis, personnel-based schemes that directly link the further education of graduate engineers in industry with on-going technological development are now recognized as a very effective mechanism not only to continually stimulate technological innovation in regional industry but also as an enticing educational strength for economic development in attracting, creating, growing, and retaining new technology-based industry.^{6,18}

Personnel-based education at the graduate level has proven to achieve the following multiple policy objectives:¹⁸

- two way technology transfer between industry and higher education (a short term objective).
- development of and placement in industry of highly skilled future leaders (medium term objective).
- sensitization of the higher education and the academic research sectors to the needs of industry (long-term).

This approach takes graduate professional education and the further development of graduate engineers in industry as the move to new higher levels of professional responsibility. At the same time, the approach achieves specific aims of sponsoring companies to advance their technological development and innovation objectives. Responding to the new challenges of lifelong education in the professions will require multi-university collaboration to develop new models for implementation and institutionalization of high quality professional education into university operations.

5.2 Next Steps: Implementation of New Model Development and Vision for Professionally Oriented Graduate Education to Develop Engineering Leaders and Technology in Industry Simultaneously Through a Pilot Collaborative University-Industry Alliance Across the Nation

We conclude by suggesting that there could be opportunities for launching a general nation-wide scheme along the lines outlined in this discussion to provide professional educational opportunities across the nation through university-industry partnership to further the growth and development of in-place graduate engineers after they enter industry to become innovators and leaders of industry. If we can provide post-graduate professional education to further develop our military leaders for leadership in national security, we can do the same for our civilian engineering leaders of industry. Competitiveness in the world market demands it.

Continual technology innovation in industry is recognized as the principal driving force for competitiveness and economic growth in the knowledge driven economy. It is engineers who guide the continual technological innovation process in industry. Consequently in order to improve U.S. competitiveness, innovative professionally oriented graduate education should be designed to further the continual professional growth, learning, and development of creative engineering leaders in industry throughout their careers — responsive to the stages of growth, professional responsibilities, and professional dimensions of creative engineering leadership.

The focus of this reform is to strengthen the nation's thrust for continual technological innovation in industry and to strengthen the nation's engineering leadership base in industry which is in responsible charge of the mandated technological innovation. Although many of the ideas presented in this paper have already been initiated in different parts of the nation and world, the effects have been piecemeal at best. What is required is integrative implementation of these proven efforts in a coherent collective sense.

Implementation of this long overdue transformation to personnel-based schemes, for professional engineering education, will not happen by itself due to many resistances at research universities. Universities, industry, and government working together as stakeholders in the nation's future for economic development must make and drive this change. The change will require multi-university collaboration in new model development, in partnership with innovative industry, for implementation and institutionalization of high quality professional education into university operations across the nation. Although strong university programs of professional engineering education have been and are being developed in isolation, a collaborative alliance of innovative universities and champions working together with shared commitment, mission and purpose brings greater strength to implementing, institutionalizing, and sustaining the needed educational transformation across the country. The change will require a different approach in funding than that which was put in place by the federal government to support research-oriented graduate education at the nation's top research universities. What is required is for industry and a small collaborative group of innovative universities to lead the way in partnership with state government agencies and federal agencies that are concerned with competitiveness and economic growth of the nation.

A new partnership model for continuity of university funding of advanced professionally oriented graduate education to enhance engineering leadership in industry and continual technological innovation must be developed which includes funding by partnering industry, by benefactors, by state economic development agencies, and by the universities in kind. This appears to be a key that can unlock the innovation potential of the nation's creative engineering base in industry and to continually improve the civilian economy through the integration of creative engineering innovation in industry and professional engineering education at the universities.

The pilot implementation of this collaborative partnership between universities-industry-government would require the next steps:

- initiation of a pilot project through a small national collaborative group of innovative universities across the nation with shared common purpose in innovative graduate education and which represent proven success in selected regions of the nation. The reform will require champions at each university in order to implement and to continually sustain this long-term innovation in higher education across the nation.
- dialogue through a national invited sponsored workshop with this collaborative group of universities with input and participation from invited industry for further exploration in more detail of the primary issues and discussion of results that evolve from the 2000 - ASEE St. Louis panel conference.
- creation of development funding for the initiation of the collaborative pilot programs with sponsorship from industry, state governments, federal matching funds, and benefactors.
- development of funding for the continual improvement/renewal of the collaborative university alliance to ensure continuity for further long-term collaborative educational innovation within the United States.

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Authors

DONALD A. KEATING received his M. Eng. in Mechanical Engineering from Cornell University. He is currently an Associate Professor of Mechanical Engineering at the University of South Carolina teaching in the areas of mechanical engineering design and leadership of technology.

THOMAS G. STANFORD received his Ph.D. in Chemical Engineering from the University of Michigan. He is currently an Assistant Professor of Chemical Engineering at the University of South Carolina teaching in the areas of thermodynamics and chemical process design.

RONALD J. BENNETT received his Ph.D. in Metallurgical Engineering from the University of Minnesota and an MBA from the University of St. Thomas. He is the Director of Graduate Programs in Manufacturing Systems and Engineering, and Chair of the undergraduate Engineering programs, at the University of St. Thomas, St. Paul, Minnesota. Dr. Bennett has more than 20 years industrial experience in engineering and management at BMC Industries, Guidant/CPI and Teltech, Inc. Dr. Bennett is also an ABET program evaluator for the Society of Manufacturing Engineers.

ROXANNE JACOBY received her M.M.E. from Cooper Union and an M.B.A. in International Management from New York University. She is an Adjunct Professor at Cooper Union, teaching Engineering Management courses. She is a Professional Mechanical Engineer, with many years of engineering and project management experience in the chemical industry and power plant fields. She is interested to further global technology management and distance education.

MEL I. MENDELSON received his B.S. from UC Berkeley, his M.S. and Ph.D. Northwestern University all in materials science. He has 20 years of industrial experience. He currently is an associate professor of mechanical engineering and director of the engineering and production management graduate program at LMU (Los Angeles, CA). His interests include failure analysis, integrated product development and creative problem solving.