Enabling the U.S. Engineering Workforce to Perform: Building a Culture for Technological Innovation and Leadership in Professional Graduate Engineering Education

D. A. Keating,[1] T. G. Stanford,[1] J. M. Snellenberger,[2] D. H. Quick,[2] I. T. Davis,[3] J. P. Tidwell,[4] D. R. Depew,[5] A. L. McHenry,[6] S. J. Tricamo,[7] D. D. Dunlap,[8]

University of South Carolina [1] / Rolls-Royce Corporation [2] / Raytheon Missile Systems [3] The Boeing Company [4]/Purdue University [5] / Arizona State University East [6] New Jersey Institute of Technology [7] /Western Carolina University [8]

Abstract

This is the fourth paper in the special panel session of the National Collaborative Task Force on Engineering Graduate Education Reform to ensure a strong U.S. engineering workforce for competitiveness. Whereas research cultures have been built into the nation's schools of engineering to enhance the educational experience of research-oriented graduate students, it is now evident that a complementary but different culture is needed also to make professionally oriented engineering graduate education more relevant to the needs of industry and to further the advanced professional education of the majority of the nation's engineers who are pursuing creative engineering practice for leadership of technology development and innovation in industry. The paper explores the type of organizational culture and attributes that must be built into high-quality professional graduate engineering education to facilitate systematic technological innovation, improve industry-university engagement for innovation, and enable the continuous positive growth of creative working professionals in industry for leadership of engineering innovation.

1. Background and History

The United States has built an excellent system of research-oriented graduate education for the education of future engineering faculty and academic scientific researchers that is second to none. Nevertheless, a major reform is needed in the U.S. system of engineering graduate education in context, organization, and culture to build complementary graduate programs of a professional nature that enhance creative engineering practice for technology development and leadership of innovation in industry.

Since implementation of the 1945 – Vannevar Bush report (*Science: The Endless Frontie*r)[1] and increased federal funding to accelerate the advancement of science at the end of World War II, the nation's schools of engineering have placed an increased emphasis on high-quality graduate education for academic scientific research. During this same time period, however, U.S. engineering education has not placed a balanced emphasis on high-quality professionally oriented graduate education for creative engineering practice and leadership of technology development and innovation in industry. As a result, engineering graduate education has emerged primarily in the United States as an outgrowth of scientific research.[2] This has produced organizational cultures and faculty reward systems that primarily support the pursuit of academic scientific research.

2. Educating Engineers as Professionals

Although the Grinter Committee recognized early on in its preliminary report that one type of education for the nation's research scientists and for the nation's professional engineers doesn't fit all,[3] the

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correctness of their view has become more apparent after four decades of an almost singular direction of research-based graduate education at the nation's schools of engineering.

While U.S. science policy placed increased emphasis on academic scientific research as the primary driver and source of U.S. technological advancement during the 1960's, 70's, 80's, and 90's, a growing awareness began to occur during the 90's that the linear research-driven model of engineering innovation was inadequate to ensure U.S. competitiveness. Fundamental changes were occurring in the United States with regard to the technological innovation process itself. A new model of purposeful, creative, and systematic needs-driven engineering development and innovation has emerged that is quite different from the linear, sequential research-driven model of engineering innovation portrayed by the 1945-Vannevar Bush model. Scientific research and engineering are no longer viewed as linear sequential activities but rather as concurrent activities with unique missions, functions, and talents of those practitioners who engage in these two very different pursuits.[4,5,6,7]

However, after four decades of building organizational cultures for academic scientific research at the nation's engineering schools and a belief system that scientific research is the primary source of U.S. technology innovation (along with building faculty reward systems that predominantly reward federally funded scientific research), it has become extremely difficult for many university faculty and administrators to undergo required change and to reflect the modern process of purposeful, systematic engineering innovation for needs-driven technology development. As Barwise and Perry have noted: "Different organisms can rip the same reality apart in different ways, ways that are appropriate to their own needs, their own perceptual abilities and their own capacities for action."[5]

3. The Concept of Culture

Juran noted that understanding the concept of different cultural patterns is extremely important in implementing effective breakthrough innovations and creating change for new levels of performance within existing institutions.[8] This understanding is more important than ever before in implementing actual engineering graduate education reform to enhance U.S. innovative capacity for competitiveness.

3.1 Defining Culture and Difference of Cultural Patterns

The concept of culture is not confined to liberal arts, the humanities, or the study of anthropology. Building an organizational culture for innovation is a key ingredient in engineering.

As Juran points out: [9]

- "Culture" is a body of learned behavior, a collection of beliefs, habits, practices, and traditions, shared by a group of people (a society) and successively learned by new members who enter the society. So says the anthropologist (Mead)."

- "This definition is important to us, for a very good reason. Anthropologists have by now studied numerous "cultures." From these studies they have observed some consistent effects when technical changes are introduced into societies. The conclusions from these studies are valid as applied to any human society, industrial or otherwise. If our district offices, factories, warehouses, etc., meet the definition of a "culture," then the great body of study of cultures is applicable to these industrial societies as well."

- "Culture, then, is just a shorthand description, a label, for the fabric of human habits, beliefs, traditions, etc. It is a fabric, not a kettle full of bits and pieces. The elements of the culture are so interwoven that disturbance of one element has effects on many others."

- “Among the ingredients of a culture is the scale of values—what is important, what is not. Cultures differ remarkably in what they consider important, and many tragedies have resulted from ignorance of these differences.”

3.2 Meeting of Two Cultures:
Resistance to Change — Difference of Cultural Patterns

William Wulf, president of the National Academy of Engineering, has pointed out that during the last two decades extensive reports for engineering education reform have been made but little action has been taken.[10] Wulf's comments were addressed primarily at the undergraduate level. But resistance to change has been even more so at the graduate level of engineering. However, the authors believe that Juran's ground breaking analysis of the impact that cultural patterns play in resisting needed innovation or in supporting needed innovation will be vitally important in raising the U.S. system of professional engineering graduate education to the next level of world-class performance to enhance our competitiveness in the innovation-driven economy.

Without a sensitization of the unique differences between the cultural pattern required for scientific research investigations and the cultural pattern required for creative engineering practice for leadership of technology development and innovation in industry, any movement for implementing sustainable reform in professionally oriented graduate education will not yield optimal results. Juran has stated that:[11]

(1) “This leads us to a cardinal rule for advocates of change: You must be aware that you *are dealing with a pattern of human habits, beliefs, and traditions which may differ from yours* and which may therefore view this change in a way totally different from your view.”

(2) “We can now state a second basic rule for advocates of change: You should, as part of your diagnosis, *discover just what will be the social effects of your proposed technical changes.* Which beliefs will be denied, which habits will require change, which attitudes will be challenged. The more precisely you can predict all this, the better able you will be to prepare your case for dealing with the inevitable resistances.”

Thus, one of the critical tasks facing change agents who are implementing professionally oriented engineering graduate education reform for positive impact on the nation's economic growth, quality of life, and defense is recognizing that the cultural patterns that are required for facilitating excellence in creative engineering practice for leadership of technology development and innovation in industry and for facilitating excellence in academic scientific research are different. It is the unique differences between the functions of scientific research investigations and those of creative engineering practice for leadership of technology development in industry that make them both vitally important to the nation's welfare for the advancement of science and for the advancement of technology (See Appendix A).

3.3 The Process of Engineering Has Changed: Lessons Learned, the
Integrative Systems Approach and Culture for Needs-Driven Engineering Innovation

Whereas detractors to engineering graduate education reform have resisted “bifurcation” of engineering graduate education largely on the basis that one size fits all and that academic scientific research is the primary driver of advanced technology developments in industry and government service, the inadequacy of the linear research model to ensure U.S. competitiveness has proven their arguments to be flawed. Although use of the Vannevar Bush model has created a much needed covenant between federal government and the nation's schools of engineering for academic scientific research, the march of events during the past four decades indicates that we need also to build a covenant between federal government, industry, and the nation's engineering schools to advance professional engineering education to the next level to better enable the U.S. engineering workforce to reach its creative, innovative, and leadership potential in engineering practice for world-class competitiveness in the innovation-driven economy. In this paper we advocate the integrated use of the engineering method and directed scientific research as a systematic and purposeful process of needs-driven technological innovation.

A paradigm shift has occurred in the U.S. Science and Technology (S&T) innovation system. A nonsequential but integrative model of proactive needs-driven engineering development that is supported concurrently by directed scientific research has evolved. Today, a growing percentage of continuous systematic technological innovation in U.S. industry and mission-oriented government service is primarily the deliberate outcome of a purposeful, planned systematic practice of innovative engineering leadership, which includes directed engineering creativity, design, and development, and which is integrated with phenomenon-oriented directed scientific research for complex technology development projects. In this deliberate process, engineering development and scientific research are not competitors in the nation's innovation system — but they are interdependent and vital components with different responsibilities. Engineering competitiveness in the global economy requires that technological innovation be undertaken primarily today from an integrative systems approach that is customer focused, needs-driven, purposeful, systematic, and continuous.

As Sanders and Brown point out:[12]

> *"The great discovery of our age is that technological innovation need not be haphazard. Industry and government have developed a new concept of planned and systematized innovation, founded on vastly expanded scientific and engineering efforts."*

3.4 Building a Culture for Engineering: Catalyst for Innovation and Strategic Advantage — Lockheed Skunk Works, Boeing Phantom Works, Allison Advanced Development Works

Understanding the differences in organizational cultural patterns is a key to mobilizing purposeful improvement and breakthrough engineering innovation for industrial competitiveness and in implementing needed reform in professionally oriented graduate engineering education at the nation's universities that support this practice. It is evident today that the organizational cultures required for scientific research investigations and for meaningful creative engineering development for needs-driven purposeful innovation are different. Consequently the educational cultures required for a scientific education and for a technological education at the graduate level for those who pursue these different pursuits must be different.

However, too many attempts in engineering graduate education reform have resulted in failure primarily because of a lack of sensitization of the cultural differences between engineering and scientific research. In other words, we have been trying to force the professional engineering culture into the established scientific research culture that has proven excellent for its intended purpose for years. As an outcome, professionally oriented engineering graduate education has met extreme resistance. These attempts have also met resistance because many believe that engineering practice is a sequential activity that follows scientific research at the universities.

Today, rather than assuming that scientific research must precede engineering in the U.S. innovation system, engineering is now recognized to be motivated proactively by a *different driver,* wherein scientific research is a contributor in the technological innovation process *rather than the initiator.* There are notable examples of world-class innovative engineering capability in the U.S. aerospace industry and mission-oriented government agencies (e.g. Lockheed-Skunk Works, Boeing-Phantom Works, Allison-Advanced Development Works, and Wright Field).

The culture for high-quality engineering innovation is not limited to the aerospace industry. The culture for innovation exists within engineering components of every forward thinking industry across the nation. However, for the most part, the organizational culture for innovation and method for engineering leadership of technology development has not been transferred as "best practice" to the nation's schools of engineering and technology nor to other regional industry across the country. To date, the nation has not optimized its potential engineering capability for world-class technology innovation and competitiveness in professional engineering education because of its almost singular emphasis at the graduate level on research.

Although the technical projects for Skunk works, Phantom works, and Advanced Development works must proceed behind "locked doors" the systematic engineering method used to develop world-class technological breakthroughs, and the types of organizational cultures that are required for this development work, as well as, the educational methods of developing world-class engineers for this creative engineering practice need not be "locked" behind closed doors. Today, the nation's schools of engineering and technology can learn much from U.S. industry by working in mutual partnership for collaboration to advance professional engineering education that better enables the U.S. engineering workforce to sustain the nation's technological progress for competitiveness and for improvement of our quality of life over the long-term.

4. Distinctions Between Professional Education and Graduate Education

The intent of this paper is to present a justification for the professional education of engineers and to point out that the culture of professional education is different from that of graduate education for research.

4.1 Towards a Justification For the Education of Professionals

Perhaps the best justification for the education of professionals can be based on Jarvis's work. As Jarvis points out:[13]

> "Dewey argues that in order for society to survive it is necessary to transmit the aims and habits of a social group from one generation to another. Clearly much of this transmission occurs in the socialization of the young, but the process is formalized in initial education, when the educators select and transmit facets of culture from one generation to the next. In a similar manner it is possible to justify the education of professionals. Each profession develops its own culture — knowledge, skills, attitudes, values, ethics, etc. and thus it must transmit these if there is to be some continuity of its existence.
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> Hence, the curriculum of basic professional education is a "selection from the culture" of the profession and the new entrants to the profession acquire some of this selection during their education, which they usually have to demonstrate during the examinations. Therefore, it is possible to justify professional education on the grounds that, for so long as the profession itself has a role in the society, it is necessary for it to survive by recruiting new entrants who have to learn its culture. Hence, professional education may be justified in terms of one of its function — that it is the means by which the profession prepares new recruits to enter it ranks, thereby ensuring the continuity of the profession.
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> Yet it might be claimed here that if this were the justification for professional education, it is making its existence dependent upon the existence of the profession. It is self-evident that this particular form of education is dependent upon the existence of a specific profession. However, this claim might fall into the trap of utilitarianism. But education must actually have an end-product, so that it is hardly surprising that professional education does discover some of its rationale for existence in the existence

of the profession itself. But the profession is not the end-product of professional education, the recruits to the profession and the practice that they undertake as a result of their education are its end-products.

Hence it may be argued that those who undertake the educational process are both part of the process and its product. The learners, are the main reason for its existence, for without learners there can be no education process and the educational institution's existence cannot be justified … Aiding those who learn to grow and develop as human beings, so that they may offer a service to others, is sufficient reason for the existence of professional education."

4.2 Educating Engineers as Creative Professionals
To Meet the Needs of Society for the Advancement and Betterment of Human Welfare

From this perspective, the National Collaborative Task Force for Engineering Graduate Education Reform is building its justification for reform on the meaning of professional education itself — especially for the practice of engineering.[14]

Thus, the National Collaborative Task Force is proceeding on six main points:

- Professional engineering education is a worthwhile enterprise, not because it is valuable in itself, but because it may enrich the lives of those who participate in it.

- The mission of engineering is service to society for its general betterment.

- Technology development is the primary driver of the nation's economic growth and defense.

- The primary creative intellectual capital for technology development rests with the creative, innovative, and leadership talent of the nation's engineers.

- Young creative talent must be encouraged to enter the engineering profession and to undergo basic professional education for entry into the profession.

- Advanced professional education must be put into place to continue the further learning, growth, and development of this engineering talent, beyond entry level, in order for engineers to grow toward their individual potentials and for the nation and corporate America to grow and compete in the innovation-driven economy.

4.3 Aims and Culture for Advanced Professional Engineering Education

If we are to unlock the creativity, innovative capacity, and leadership potential that exist in our "intellectual engineering capital" within corporate America and the nation's schools of engineering and technology, then educational change is mandatory at the advanced professional level of engineering. And we must begin to think outside of the box. It is now evident that the aims of advanced professional education for the practice of engineering and the aims of graduate education for research are different. Engineering and scientific research investigations are two entirely different but complementary pursuits that require different talents, types of educations, methods, and organizational cultures to achieve optimal performance. Many faculty who teach in research-oriented graduate programs will be valuable for their technical expertise in professionally-oriented graduate programs. As Teare and Hollister pointed out years ago: the essence of the practice of engineering is creative problem-solving, engineering design in its "broadest sense", and professional engineering leadership to meet real-world needs of society in the spirit and mission of the practicing profession (service).[15,16]

We have been striving too long and have been constraining the profession too long in treating reform in advanced professional education, for the practice of engineering and leadership of technology development in industry, as if it had the same mission, purpose, method, and culture as graduate education for scientific research. It doesn't. The competencies, professional dimensions, scholarship, and culture which are required to advance the practice of engineering for world-class technology development and which are required to advance world-class science are not the same (See Appendix A). Nor do these capabilities exist within the same practitioner except for the most unusual cases. Whereas the aim of "basic professional" engineering education is to prepare students for entry into practice, the National Collaborative Task Force believes that the overall aim of "advanced professional" engineering education is to continue the lifelong learning, growth, and development of the practitioner beyond entry level toward his or her creative, innovative, and leadership potential in engineering practice. The National Collaborative Task Force addressed the skill-sets, professional dimensions, and framework for this new type of advanced professional education at the 2003 ASEE Annual Conference.[17]

4.3 Defining Attributes of High-Quality Advanced Professional Education that Enables Lifelong Learning and Growth for Innovative Engineering Practice and Technology Leadership

Based upon the national study for the Council of Graduate Schools (1993),[18] and their comprehensive follow-on work (1997),[19] Conrad, Haworth, and Millar have identified five clusters of attributes for developing and sustaining high-quality postgraduate professional education which contribute to enriching the working professional's learning experiences and that positively affect the professional's growth and development. These findings advance a new perspective on program quality that is centered on the concept of engagement of working professionals that is quite different from the conventional view of program quality for research-based graduate education that is centered primarily on the academic research productivity and credentials of the faculty. Those attributes that are required in developing and sustaining high-quality professional graduate programs center around five primary clusters. (See Appendix B)
The National Collaborative Task Force has also defined a framework of integrative professional graduate education and practice that enables lifelong learning and growth of working professionals as technology leaders throughout their professional engineering careers in industry (See appendix C).

5. Drawing the Right Conclusions

A new paradigm has evolved for the modern practice of engineering that has outmoded the previous model of 1945. Because of the distinctive professional characteristics, types of knowledge, experience, methods, and skill-sets that differentiate the modern practice of engineering for excellence in technology development from that required for excellence in scientific research, it is now evident that these distinctive features prescribe different organizational cultures and types of advanced education at the graduate level. The professional engineering thought process and supporting culture that is required to conceptualize and lead the continuous development of new and improved technology for industry and government operations is quite different from that required for scientific research investigations. Understanding organizational cultural patterns is a key to mobilizing purposeful improvement and engineering education graduate reform. The National Collaborative Task Force on Engineering Graduate Education Reform is not proposing to change research-oriented graduate education to reflect engineering practice. It would be foolish to change this excellent approach and culture that has proven successful for the U.S. advancement of science. Our intent, however, is to develop a complementary approach and culture that facilitates excellence in professional scholarship, creative engineering practice, and the advancement of U.S. technology by implementing a new type of advanced professional engineering education and culture that promotes U.S. industrial competitiveness and that enables lifelong growth of the nation's engineers in industry.

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Biography – National Collaborative Task Force – Panel on Organizational Culture for Innovation

DONALD A. KEATING is associate professor of mechanical engineering, University of South Carolina, former dean Engineering and Science Institute of Dayton and former technical director, Air Mobility Program, Hqs USAF Aeronautical Systems Division.

THOMAS G. STANFORD is assistant professor of chemical engineering, University of South Carolina.

JAY M. SNELLENBERGER is manager, employee development, strategic engineering and business improvement, Rolls-Royce Corporation, Indianapolis, Indiana, and vice chair of the ASEE-Corporate Members Council.

DAVID H. QUICK is manager, R&D customer requirements, Rolls-Royce Corporation, Indianapolis, Indiana, and past chair, ASEE-Corporate Members Council.

ISADORE T. DAVIS is manager, engineering university relations, Raytheon Missile Systems, Tucson, Arizona, chair, ASEE-Corporate Members Council, member ASEE Board of Directors.

JOSEPH P. TIDWELL is southwest regional university relations coordinator, The Boeing Company.

DENNIS R. DEPEW is professor and dean of the school of technology, Purdue University.

ALBERT L. McHENRY is dean of the college of technology and applied sciences at Arizona State University East, and former Chair of the Engineering Technology Council of the American Society of Engineering Education.

STEPHEN J. TRICAMO is professor of industrial and manufacturing engineering, and former dean of engineering and technology, New Jersey Institute of Technology.

DUANE D. DUNLAP is professor and department head of engineering technology, Western Carolina University.

Appendix A

Functions of Creative Engineering Practice and Scientific Research

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Creative Engineering Practice

Creative Technology Development

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

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

Scientific Research

Basic and Directed (Applied) Research

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

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

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

Appendix B

Attributes for Developing and Sustaining High-Quality Professional Graduate Programs that are Concurrent with Engineering Practice For Working Professionals in Industry

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Attributes of High-Quality Postgraduate Professional Programs For the Practice of Engineering and Leadership of Technology

Based upon the national study for the Council of Graduate Schools (1993), and their comprehensive follow-on work (1997), Conrad, Haworth, and Millar have identified five clusters of attributes for developing and sustaining high-quality postgraduate professional education which contribute to enriching the working professional's learning experiences and that positively affect the professional's growth and development. These findings advance a new perspective on program quality that is centered on the concept of engagement of working professionals that is quite different from the conventional view of program quality for research-based graduate education that is centered primarily on the academic research productivity and credentials of the faculty. Those attributes that are required in developing and sustaining high-quality professional graduate programs center around five primary clusters.

- *Cluster One: Diverse and Engaged Participants*
  - Diverse and Engaged Experienced Faculty
  - Diverse and Engaged Experienced Students
  - Engaged and Experienced Program Leaders
- *Cluster Two: Participatory Learning Cultures*
  - Shared Program Direction
  - Community of Learners
  - Risk-Taking Environment
- *Cluster Three: Interactive Teaching and Learning*
  - Critical Dialogue
  - Integrative Learning
  - Mentoring
  - Cooperative Peer Learning
  - Out-of-Class Activities
- *Cluster Four: Connected Program Requirements*
  - Planned Breadth and Depth Course Work
  - Professional Residency
  - Tangible Product
- *Cluster Five: Adequate Resources*
  - Support for Students
  - Support for Faculty
  - Support for Basic Infrastructure

Appendix C

Framework of Integrative Professional Graduate Education and Practice that Enables Lifelong Learning and Growth of Working Professionals As Technology Leaders in Industry

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Integrative Professional Graduate Education

- *Holistic*
- *Context of Engineering Practice for Technology Development and Innovation in Industry*
- *Graduate Participants are Experienced Professionals*
  Engaged in Advanced Engineering Practice in Industry
- *Faculty are Experienced Professionals*
  Engaged in Advanced Engineering Practice and Professional Scholarship
- *Participatory Learning Cultures for Teaching, Learning, and Innovation*
- *Integrative Professional Graduate Education Concurrent with Engineering Practice*
  - *a) Core Professional Graduate Studies Relevant to Engineering Practice for Leadership of New Technology Development and Innovation in Industry*
  - *b) Technical and Socio Electives Relevant to the Professional's Field of Technology*
  - *c) Technology-Based Project Learning (Substantive Technology Development Project Directly Relevant to the Needs of the Professional's Sponsoring Industry)*
  - *d) Experiential Learning*
  - *e) Self-Directed Learning*
- *Developing Innovative Technology in Industry and Engineering Leaders Simultaneously*
- *A "System of Lifelong Learning" Designed to Support the Critical Skill-Sets of Advanced Engineering Practice and to Enable Practicing Engineers to Achieve their Creative, Innovative, and Leadership Potential throughout their Professional Careers*