AC 2008-506: ENSURING A STRONG U.S. ENGINEERING WORKFORCE FOR TECHNOLOGY INNOVATION AND COMPETITIVENESS: CREATING A CULTURE FOR INNOVATION IN INDUSTRY

Roger Olson, Rolls-Royce Corporation

Roger N. Olson

Professional Experience:

Lead Stress Engineer for the Combustors, Transmissions, and Structures Operational Business Unit at Rolls-Royce Corporation, Indianapolis, Indiana. Duties include the mentoring of structural analysts, overseeing structural analysis work, participating in design reviews, reviewing/approving technical reports, reviewing/approving design layouts.

Formerly, Manager, Structural Analysis - Fans, Compressors, & Turbines), at Rolls-Royce. This included directing/coaching/mentoring degreed engineers in the performance of detailed finite element analyses and life analyses, in support of the preliminary design, final design, upgrade, engine testing, and the failure analysis of military, commercial, helicopter, and industrial gas turbine engine components.

Chief Secretary/Treasurer of the Rolls-Royce Indianapolis, Engineering Education Committee.

Member of the Indiana State Leadership Team for Project Lead the Way

Member of the steering committee for the Rolls-Royce Purdue Master of Science in Technology Cohort degree program.

Prior to my work at Rolls-Royce, I worked in various engineering and management capacities at Pratt & Whitney.

Manager of the Design Life Development group at Pratt & Whitney, Florida Operations. This entailed leading a team of degreed engineers and engineering technicians in the development of Low Cycle Fatigue and Damage Tolerance life design systems for gas turbine and rocket engines

Other Pratt & Whitney experience included managing teams of structural and life analysts working on all areas of gas turbine engines, and on high pressure turbopumps for liquid fueled rockets (SSME).

Education:

BME (5 year) degree in Mechanical Engineering from the University of Minnesota

MSME degree in Mechanical Engineering from the University of Connecticut

Professional Societies:

Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA), Education Officer for the Indiana Section of AIAA, and a former member of the AIAA Technical Committee on Structures.

Member of the American Society for Engineering Education, and a Director of the CIP (College Industry Partnership) Division of ASEE.

Randall Holmes, Caterpillar Inc.

Randall J. Holmes

Professional Experience:

Workforce Development Manager - Caterpillar Inc. Lafayette Large Engine Center
Responsibilities: Oversee recruiting and selection processes, lead development and learning efforts for technicians and professional employees, manage annual succession planning process and manage employee engagement process for Caterpillar's Lafayette IN, facility

Former HR 6 Sigma Black Belt – Project manager for both corporate and facility specific Human Resources transformation projects domestically and China

Indiana Advanced Manufacturing Education Collaboration advisory board member

Lafayette/West Lafayette Workforce Development Council member

Education:

BS in Management from Indiana Wesleyan University

MS in Management from Indiana Wesleyan University

Professional Societies:

Member of the American Society for Engineering Education

Donald Keating, University of South Carolina

Thomas Stanford, University of South Carolina
THOMAS G. STANFORD is assistant professor of Chemical Engineering, University of South Carolina.

Ensuring a Strong U.S. Engineering Workforce for Technology Innovation and Competitiveness: Creating a Culture of Innovation in Industry

1. Introduction

This is the third of four invited papers prepared for a special session of the National Collaborative Task Force on Engineering Graduate Education Reform that is focusing on the need to create a culture of innovation in industry to ensure a strong U.S. Engineering Workforce for Technology Innovation and Competitiveness. This culture of innovation: is needed to ensure that the U.S. stays at the top of the game in the industrial world. Creativity is by far one of America's most reliable competitive advantages. But what sparks creativity and how does it get engineered into products? Does it come from a fortunate few that miraculously hit on the next best thing?

In reality, creativity is an on-going process that requires a collaboration of talent, knowledge and experiences from many different aspects of the value chain, from the shop floor of our manufacturing facilities to engineering to the marketing team to the customer. True creativity is far from a science; it is more of an art. There is no one recipe that produces innovation and creativity, but it tends to evolve from many ideas, perspectives and experiences that are placed on the table of design and seasoned with the chemistry of a team and its leader. Leading innovation teams requires that the leader not only knows and applies the tools of his/her craft, but also has the leadership capabilities to facilitate collective intelligence, including recognizing, and listening to, the voice of the customer. This paper addresses the issues and known attributes required in building effective cultures that foster creativity, innovation, and the leadership abilities of the nation's engineers within industry.

2. Addressing the Voice of the Customer

Over the last several years industry has learned that listening to the voice of the customer is vital not only to product design, but also to the rate at which new or improved products make their way to the customer. Although this in itself is not a new concept, building a culture of innovation within the corporate infrastructure may be a bit more unfamiliar to today's industry. While having customers actually sitting at the design table giving their input early in the creation process (such as what Boeing did early in the 787 program) can greatly help the success rate of the overall design, it also takes a very talented leader to blend the voice of the customer with the voice of the business to create a true culture of innovation. This type of culture is especially important to product design, as well as to the sustainability of further growth as technology-based organizations dominate industrial productivity.

2.1 Building a Culture of Innovation

In today's innovation-driven economy, the vast majority of engineering innovations are needs-driven and market-focused, requiring deliberate engineering problem-solving and responsible leadership. Today the practice of engineering for creative technology development and innovation is a very purposeful and systematic practice. It is not the linear or sequential process following basic research as portrayed in 1945, by Vannevar Bush [1]. Rather, creative engineering projects in industry frequently drive the need for directed strategic research efforts at universities, when necessary, or when anticipated, to gain a better understanding of the natural phenomena involved. With this in mind, the ability to build and sustain a culture of innovation is becoming the skill that is truly needed to sustain America's viability, yet in many organizations, it is left to chance. Engineering education would rather place their efforts on more technical tools instead of teaching the art of collaboration.

3. Creating Cultures of Innovation

In this age of technology, the availability of high-tech tools has enabled engineers to design better products faster than ever before. Industry has learned that the voice of the customer is vital to the product design, and now the customers are playing a key role in the product design and development from the very beginning. Production employees are consulted on manufacturability, ergonomics, and practical application; and all of this is done in open rooms or even on the factory floor instead of in secret rooms of the past where only a small design team had input into the next new products. We now design on the fly. We utilize software to create electronic prototypes and simulators to insure design integrity before the first parts are ever manufactured on the production floor. This is a far cry from what Henry Ford experienced in the early days of the automobile. Having the right tools, however, doesn't create a great product. It takes more than technology, it takes the right culture of innovation and invention, although creating it is not necessarily an easy thing to do.

In today's global market, the United States' ability to remain among the World's best, hinges entirely on our ability to invent on a scale like never before. The engineers who are in demand by the leading companies are those who have transformed themselves into "imagineers." In this new role, engineers not only need the technical skills of their discipline, but just as importantly, they need skills in culture creation where collaboration flows freely. Within this culture, failure is viewed and celebrated as successfully breaking through the constraints of reason and creative boundaries otherwise left unexplored. This new engineer serves as a catalyst, by orchestrating collective intelligence, driving the team farther from the bell curve's mean, creating a new "innovation curve." It is here; beyond of the central 68%, of the bell curve, where the "innovation curve" begins, and engineering break-throughs are realized. Ultimately, cultural engineering is as important to the creation of the final product as technical engineering, and it is the "imagineers" who will pull it all together.

Creating cultures of innovation has never before been more crucial to America's competitive advantage than it is today. Enabling innovative cultures will require effective engineers, and effective engineering leaders, who employ professional skills, attained through both experience and through a professional graduate education, in addition to the technical and analytical skills of their undergraduate studies. Engineering experience, coupled with professional graduate studies, will transform engineers into leaders who can orchestrate collaborative creativity, invention, and innovation. However, building cultures of innovation will not be easy, nor will these cultures be built overnight. To build and sustain a technology-based organization for innovation, a progressive transformation must occur.

The need to prepare our future leaders within the engineering discipline has truly changed. Tooling them with a different set of skills is becoming more and more important. The ability to select team members, facilitate open discussions, and resolve conflicts is now as important as the technical knowledge of engineering. Building a culture for innovation is the foundation that all success is built on, and this cannot be left to chance, it must be taught and emphasized throughout an engineer's graduate education.

We must acknowledge, and remember the following:

- Creativity is our competitive cutting edge.
- Don't re-invent the wheel - improve it.

3.1 The Need for Experience

- Although the engineer, upon graduation with a Baccalaurate degree knows the basic principles of his/her field, he/she most likely has not learned how to properly apply his/her knowledge, and generally learns this from on-the-job experience and training, as well as from mentoring by more experienced engineers. The engineer must receive effective feedback along the way, to know how he/she is progressing to realize his/her true strengths and areas where further development is needed.
- Therefore, annual performance ratings for each engineer must be prepared in a proper manner, and must be reviewed one-on-one between the manager and the engineer.
- The field of engineering is changing so rapidly, that the engineer must keep up with his/her field.
- Most graduate study programs are aimed at the engineer that intends to pursue research traveling down the academic route.

3.2 The Need for Professional Engineering Graduate Studies

To meet this challenge, the National Collaborative Task Force is engaged in a complex project that requires a total systems approach. The stakes to enhance the innovative capacity of the U.S. engineering workforce for competitiveness are high.

- Advanced degrees for professional engineers:
    - A Professional Masters degree, with a company oriented directed project rather than a research thesis
    - A Professional Doctorate of Engineering degree, with a company oriented directed project rather than a research thesis
    - A Professional Fellow (recognized by his/her peers as having progressed well beyond the norm).
    - Industry experienced faculty are needed to teach the professional engineers. Some of these could/should be visiting/adjunct faculty who are experienced practicing engineers.

3.3 Transforming Engineers into Leaders

- In many engineering organizations today, there are multiple tracks for advancement. To be successful in any of these tracks, professional graduate engineering education is needed.
    - One track is to progress toward increased specialization and increased value to the company. These engineers need a professional graduate education in their field of specialization.
    - Another track is to become a Project Manager.
    - The third track is to progress into a management role, and become a leader.
        - For an engineer to succeed in the management track, leaders must groom the engineer for a leadership role. One way to do this is to provide a professional graduate engineering education which includes both engineering and management classes.

4. Professional Engineering Graduate Education

Professional engineering graduate education will play a vital role in the transformation of engineers into leaders .To meet this challenge, the National Collaborative Task Force is evolving a series of preliminary guidelines for engineering graduate education reform to develop a professionally oriented graduate education to enhance the innovative capacity of the U.S. Engineering Workforce in industry (see Appendix B). Engineering leaders must be developed that will guide engineers that will innovate new designs, leading to products that will meet what the customer wants and needs. Management styles are needed that will encourage, not discourage innovation, and will meet the basic human needs of the engineers. From the organizational beliefs of McGregor and the human motivation needs as defined by Maslow, to cutting-edge concepts and best practices from other nations, which will lay the groundwork for turning theory into practice.

4.1 Management Styles and Subordinate Responses Impacting Working Conditions

Douglas McGregor [2] has defined two management theories (beliefs).

Belief X is an authoritative management style. The Belief X Assumptions are:

- The average human being has an inherent dislike of work and will avoid it if he can.
- Because of their dislike for work, most people must be controlled and threatened before they will work hard
- The average human prefers to be directed, dislikes responsibility, is unambiguous, and desires security above everything.

These assumptions are a basic belief system that lie behind most organizational principles today, and give rise both to "tough" management with punishments and tight controls, and "soft" management which aims at harmony at work. Both of these are "wrong" because man needs more than financial rewards at work, he/she also needs some deeper/higher order motivation - the opportunity to fulfill himself/herself.

Theory X managers do not give their staff this opportunity, so that the employees behave in the expected fashion.

Belief Y is a participative management style. The Belief Y Assumptions are:

- The expenditure of physical and mental effort in work is as natural as play or rest.
- Control and punishment are not the only ways to make people work, man will direct himself if he is committed to the aims of the organization.
- If a job is satisfying, then the result will be commitment to the organization.
- The average man learns, under proper conditions, not only to accept but to seek responsibility.
- Imagination, creativity, and ingenuity can be used to solve work problems by a large number of employees.
- Under the conditions of modern industrial life, the intellectual potentialities of the average man are only partially utilized.

4.1.1 Comments on Belief X and Belief Y Assumptions:

- These assumptions are based on social science research which has been carried out, and demonstrate the potential which is present in man, and which organizations should recognize, to become more effective.
- McGregor sees these two beliefs as two quite separate attitudes. Belief Y is difficult to put into practice on the shop floor in large mass production operations, but it can be used effectively in the managing of managers and professionals.
- In "The Human Side of Enterprise" McGregor shows how Belief Y affects the management of promotions and salaries and the development of effective leaders and managers. McGregor also sees Belief Y as conducive to participative problem solving.
- It is part of the manager's job to exercise authority, and there are cases in which this is the only method of achieving the desired results when subordinates do not agree that the ends are desirable.
- However, in situations where it is possible to obtain commitment to objectives, it is better to explain the matter fully so that employees grasp the purpose of an action. They will then exert self-direction and control to do better work - quite possibly by better methods - than if they had simply been carrying out an order which the y did not fully understand.
- The situation in which employees can be consulted, is one where the individuals are emotionally mature, and positively motivated towards their work; where the work is sufficiently responsible to allow for flexibility, and where the employee can see her or his own position in the management hierarchy. If these conditions are present, managers will find that the participative approach to problem solving leads to much improved results compared with the alternative approach of handing out authoritarian orders.

- Once management becomes persuaded that it is under estimating the potential of its human resources, and accepts the knowledge given by social science researchers and displayed in the Belief Y assumptions, then it can invest time, money and effort in developing improved applications of the theory.
- McGregor realizes that some of the theories he has put forward are unrealizable in practice, but wants managers to put into operation the basic assumption that:
    - Staff will contribute more to the organization if they are treated as responsible and valued employees.
- Creative people/engineers are motivated from within, and want to work.
- McGregor says, in his own words, "Theory Y is an invitation to innovation."

Professional engineers in industry will respond better to the participative management style of Belief Y, and will be much more innovative in organizations that seek input from everyone. Based on Belief Y, the National Collaborative initiative builds upon P. R. Whitfield's [5] central premise that "It is taken as self-evident that the creative output of the [nation's] engineering will be raised quickest and over the widest area by successful efforts to improve the creativity of the engineer already in industry, specifically the engineer who has added an adequacy of experience to his or her basic technical training." Whitfield says that the engineer, as part of human society, cannot live work, or create (i.e. innovate) in complete isolation. He also said that the shift in emphasis from the individual inventor (in times past) to the organized team approach raises difficulties. What he meant by that, is the credit for success in a team effort would go more to the employer than to the individual.

4.2 The Hierarchy of Human Needs, and the Effect on the Work Force

Abraham Maslow defined a hierarchy of human needs [3,4]. Maslow developed a theory of personality that has influenced a number of different fields, including education. This wide influence is due in part to the high level of practicality of Maslow's theory. This theory accurately describes many realities of personal experiences. Many people find they can understand what Maslow says. They can recognize some features of their experience or behavior which is true and identifiable, but which they have never put into words.

Maslow's basic needs are as follows:

- Physiological Needs
    - These are biological needs. They consist of needs for oxygen, food, water, and a relatively constant body temperature. They are the strongest needs because if a person were deprived of all needs, the physiological ones would come first in the person's search for satisfaction.
- Safety Needs
    - When all physiological needs are satisfied and are no longer controlling thoughts and behaviors, the needs for security can become active. Adults have little awareness of their security needs except in times of emergency or periods of disorganization in the social structure (such as widespread rioting). Children often display the signs of insecurity and the need to be safe.

- Needs of Love, Affection and Belongingness
  - When the needs for safety and for physiological well-being are satisfied, the next class of needs for love, affection and belongingness can emerge. Maslow states that people seek to overcome feelings of loneliness and alienation. This involves both giving and receiving love, affection and the sense of belonging.
- Needs for Esteem
  - When the first three classes of needs are satisfied, the needs for esteem can become dominant. These involve needs for both self-esteem and for the esteem a person gets from others. Humans have a need for a stable, firmly based, high level of self-respect, and respect from others. When these needs are satisfied, the person feels self-confident and valuable as a person in the world. When these needs are frustrated, the person feels inferior, weak, helpless and worthless.
- Needs for Self-Actualization
  - When all of the foregoing needs are satisfied, then and only then are the needs for self-actualization activated. Maslow describes self-actualization as a person's need to be and do that which the person was "born to do." "A musician must make music, an artist must paint, and a poet must write." These needs make themselves felt in signs of restlessness. The person feels on edge, tense, lacking something, in short, restless. If a person is hungry, unsafe, not loved, or not accepted, or lacking self-esteem, it is very easy to know what the person is restless about. It is not always clear what a person wants when there is a need for self-actualization.

The hierarchic theory is often represented as a pyramid, with the larger, lower levels representing the lower needs, and the upper point representing the need for self-actualization. Maslow believes that the only reason that people would not move well in the direction of self-actualization, is because of hindrances placed in their way by society. He states that education is one of these hindrances. He recommends ways education can switch from its usual person-stunting tactics to person-growing approaches. Maslow states that educators should respond to the potential an individual has for growing into a self-actualizing person of his/her own kind.

Ten points that educators should address are listed:

1. We should teach people to be authentic, to be aware of their inner selves and to hear their inner-feeling voices.
2. We should teach people to transcend their cultural conditioning and become world citizens.
3. We should help people discover their vocation in life, their calling, fate or destiny. This is especially focused on finding the right career and the right mate.
4. We should teach people that life is precious, that there is joy to be experienced in life, and if people are open to seeing the good and joyous in all kinds of situations, it makes life worth living.

5. We must accept the person as he or she is, and help the person to learn their inner nature. From real knowledge of aptitudes and limitations we can know what to build upon, what potentials are really there?
6. We must see that the person's basic needs are satisfied. This includes safety, belongingness, and esteem needs.
7. We should refreshen consciousness, teaching the person to appreciate beauty and the other good things in nature and in living.
8. We should teach people that controls are good, and complete abandon is bad. It takes control to improve the quality of life in all areas.
9. We should teach people to transcend the trifling problems and grapple with the serious problems in life. These include the problems of injustice, of pain, suffering, and death.
10. We must teach people to be good choosers. They must be given practice in making good choices.

4.3 The Evolving of Preliminary Guidelines for Professional Engineering Graduate Education by the National Collaborative Task Force

A new type of professionally oriented engineering graduate education is required that develops the innovative capacity of the U.S. engineering workforce for competitiveness, and that better supports the innovation skills required of engineers at all levels of leadership responsibility in industry. The National Collaborative Task Force is leading the development of a new model of professional education for graduate engineers in industry focusing on innovation, and leadership, and solving unknown problems. Educating engineers as creative professionals is a career long process of growth and further professional development, including the development of intrinsic creative and innovative potential for leadership in engineering practice. This process extends beyond entry level undergraduate education to the highest levels of responsible engineering leadership within the practicing profession of engineering. Professional education at this level requires an integrative combination of self-directed learning, experiential learning, innovation-based learning, and advanced studies combined with real-world experience in creative engineering practice.

The National Collaborative Task Force believes that the development of the engineer in industry or government service as a creative professional, innovator, and leader can be classified by three stages of growth:

- Early Career Development — From Level I Engineer through Level IV Engineer
- Mid-Career Development — From Level IV Engineer through Level VI Engineer
- Senior Career Development — From Level VI Engineer through Level IX Engineer

See Appendix A for a more detailed description of the responsibilities and expectations at each engineering level.

5. Conclusions: A Work in Progress ─ Why a Professional Postgraduate Education for Engineers in Industry is Needed

The United States needs a workforce that is nurtured at all levels of engineering practice beyond entry level to fuel America's preeminence for world-class technology development and innovation. Professional engineering education does not end at entry level or with a professional master's level education, if we want to unleash America's engineering potential for competitiveness and national security purposes. Second, close collaboration between industry and universities will be critical to the success of this reform. The Task Force believes that the further graduate development of the U.S. engineering workforce in industry can neither be done by universities working alone, nor by industry working alone. Third, reinventing professional engineering education for creative engineering practice requires industry's steady and consistent input aimed at what we want the nation's engineers to do and to become. The next steps of the National Collaborative Task Force are to implement these recommendations into action in the national interest [10,11].

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Appendix A

Stages of Professional Maturation, Autonomy, and Responsibilities in Engineering Practice for Responsible Technology Leadership

Stages of Growth	**Typical Responsibilities-Autonomy-Judgment**
ENGINEER IX	An engineer-leader at this level is in responsible charge of programs so extensive and complex as to require staff and resources of sizeable magnitude to meet the overall engineering objectives of the organization.
ENGINEER VIII	An engineer-leader at this level demonstrates a high degree of creativity, foresight, and mature judgment in planning, organizing, and guiding extensive engineering programs and activities of outstanding novelty and importance. Is responsible for deciding the kind and extent of engineering and related programs needed for accomplishing the objectives of the organization.
ENGINEER VII	In a leadership capacity, is responsible for an important segment of the engineering program of an organization with extensive and diversified engineering requirements. The overall engineering program contains critical problems, the solutions of which require major technological advances and opens the way for extensive related development.
ENGINEER VI	In a leadership capacity, plans, develops, coordinates, and directs a number of large and important projects or a project of major scope and importance. Or, as a senior engineer, conceives, plans, and conducts development in problem areas of considerable scope and complexity. The problems are difficult to define and unprecedented. This involves exploration of subject area, definition of scope, and selection of important problems for development.
ENGINEER V	In a leadership capacity, plans, develops, coordinates, and directs a large and important project or a number of small projects with many complex features. Or, as an individual principle engineer, carries out complex or novel assignments requiring the development of new or improved techniques and procedures. Work is expected to result in the development of new or refined equipment, materials, processes, or products. Technical judgment, knowledge, and expertise for this level usually result from progressive experience.
ENGINEER IV	Plans, schedules, conducts, or coordinates detailed phases of engineering work in part of a major project or in a total project of moderate scope. Fully competent engineer in all conventional aspects of the subject matter of the functional areas of assignments. Devises new approaches to problems encountered. Independently performs most assignments requiring technical judgment.

ENGINEER III	Performs work that involves conventional types of plans, investigations, or equipment with relatively few complex features for which there are precedents. Requires knowledge of principles and techniques commonly employed in the specific narrow areas of assignments.
ENGINEER I/II (Entry Level Engineer)	Requires knowledge and application of known laws and data. Using prescribed methods, applies standard practices/techniques under the direction of an experienced Engineer.

Appendix B

Guidelines for Engineering Education Reform to Develop Professionally Oriented Graduate Education to Enhance the Innovative Capacity of the U.S. Engineering Workforce in industry

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GUIDELINES FOR NATIONAL COLLABORATIVE TASK FORCE

- Focus on innovation and leadership

- Focus on development of U.S. Engineering Workforce for innovative competitiveness in industry, second to none in the world

- Vision ─
  "Innovation fosters the new ideas, technologies, and processes that lead to better jobs, higher wages and a higher standard of living. For advanced industrial nations no longer able to compete on cost, the capacity to innovate is the most critical element in sustaining competitiveness."

  Council on Competitiveness

- Workforce Development ─
  "The Council's business leaders agree that every company's most important asset are the people who walk in its doors every morning. Talented people creating new ideas and innovative technologies keep the economy strong, and growing stronger. The education and training that spark Americans' creativity and give them cutting-edge skills are a key to competitiveness.

  Council on Competitiveness

- Create a new, innovative professional curriculum combined with engineering practice that matches and supports the progressive core-competence skills required for effective engineering leadership of technology development & innovation in industry ─ from beginning Entry Level Engineer through the Chief Engineer / Vice President of Engineering & Technology level for corporate technology responsibility

- Graduate centers that will be "statewide clusters" for advanced professional education for engineering innovation and leadership in all 50 states across the nation

- Use the combined formidable teaching and human resource strengths of regional universities and industry in this process

- Form a unique collaborative partnership between industry and universities in developing the creative and innovative capacity of the U.S. Engineering Workforce in industry for world-preeminence in technology development & innovation

- Enable and encourage "life-long learning" within the engineering population of a company to stimulate innovation