Growing the National Innovation System: Assessing the Needs and Skill Sets for Innovative Professional Graduate Education Defined by the Tasks and Responsibilities of Engineer-Leaders in Industry

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Abstract

This is the second paper in the special panel session on reshaping engineering graduate education to better serve the needs of the practicing professional. Although several incremental changes have been made to improve undergraduate education as preparation for entry into practice, sweeping changes are needed in graduate education to address areas of neglect that hinder the ability of the U.S. technical workforce to fully contribute to the nation's need for economic growth. Central to this transformation is a change in the perspective of graduate education, including contextual and experiential learning activities, required to support the modern process of engineering in creating new innovative technology in industry. A new vision for the graduate education of engineers as creative professionals is evolving, a vision based upon career-long needs of professionals as a growth process for leadership of technological innovation. This paper focuses on the critical skill-sets, knowledge, and experience that engineers need as technology leaders beyond basic, four-year undergraduate education to stimulate constant technological innovation for enhanced U.S. competitiveness in the new economy. The paper outlines the functional requirements and a new approach to the design of professional graduate education as an integrated system for lifelong learning that supports innovative practice throughout the working professional's career.

1. Introduction

As we enter the 21st century, the process of engineering for creating technology has changed substantially from singular reliance on a linear basic research-driven model of innovation to an integrative model of purposeful, needs-driven, systematic engineering innovation that frequently drives directed-strategic research. U.S. graduate education must reflect this change for the nation to maintain its competitive edge. In today's innovation-driven economy, the U.S. engineering workforce plays a vital role in creating new technology and in leading the process of continuous technological innovation for competitive advantage.

The demand for high-caliber engineers/technologists with strong technical skills, practical experience, and professional skills for leadership of technology development in industry is increasing. Although U.S. engineering education has pioneered various professional options including five-year undergraduate and professional master's models, as preparation for practice, it has not gone far enough. A system that fosters high-quality professional graduate education throughout the working professional's career in combination with engineering practice needs to be developed to augment the nation's strength in research-based graduate education. The purpose of this paper is to establish a set of professional specifications for the design of professional graduate education as an integrated "system for lifelong learning" that supports innovative engineering practice and technology leadership in industry. The framework for this new innovative approach is based upon a comprehensive review of qualification standards, already established in industry and government service.

1.1 Defining a New Rationale for Lifelong Learning As a Growth Process In Educating and Developing Leaders in Technology

In the past, the concept of lifelong learning for engineers and technologists has been built upon a very limiting model of higher education and upon the academic perspective that the nation's engineers and technologists are used primarily in industry as simply the "appliers" and transfer agents of new scientific "discoveries" and research findings (originating at the nation's research universities) into products and process for industrial innovation. This perspective (originating in 1945 U.S. Science Policy)[1] has focused on developing the nation's university researchers as the primary generators of new U.S. technology. Because of this belief, U.S. engineering education has been limited primarily to undergraduate education as preparation for entry into practice. Little consideration (with notable exceptions) has been given to the design of high-quality professional education for the nation's domestic engineers and technologists beyond entry level. Graduate education for the nation's engineers and technologists has evolved largely as a by-product of research-based graduate education for the nation's academic research scientists.[2]

This unbalanced focus has given very little room to the recognition of or use of the nation's domestic engineers/technologists in industry as creative professionals or to provision for their further professional graduate education — when in reality they are the nation's primary resource for creating, designing, developing, and leading the nation's continuous thrust for new, improved, and breakthrough technological developments. Most U.S. graduate engineers/technologists enter industry/government service upon completion of their baccalaureate requirements. Of these graduates, most are pursuing engineering leadership careers for the development of new/improved technology. Thus, it is now evident that a "disconnect" has existed between U.S. engineering education and engineering practice at the graduate level for several years.

Accordingly, U.S. universities and their schools of engineering and technology must expand their roles if they are to be effective in the 21st century by increasing their capacity for engagement in professional graduate education with industry to better meet U.S. technology needs and the further graduate needs of the nation's emerging technology leaders. As Robert Spitzer, vice president of Boeing Company, points out:

- "Corporations want and need to engage with universities. Universities and their contributions to research, education, and community service are an obvious part of the value stream for corporations … That education must promote the development of the prerequisite critical skills and thinking needed in the future workforce is a given, but there must also be the development of a culture that fosters an understanding of lifelong learning for our employees and communities … The educational engagement of corporations with universities is focused on the preparation of new talent and the continuing education of existing employees.

- "It never has been possible to teach bachelor's level individuals every thing they will ever need to know. The educational system, however, has behaved for many years as if this were a possible achievement … ABET Engineering Criteria formally recognizes that this educational model is not feasible … Educational institutions need to develop a comprehensive, integrated engineering education … if companies like Boeing are to be successful and remain competitive in the new global economy and marketplace."[3]

1.2 How does Engineering Differ from Science?

But the challenge of promoting educational engagement with industry, which Spitzer and others call for, requires purposeful, planned transformation to develop graduate education as an integrated system for lifelong learning that is concurrent with the working professional's on-going practice of engineering in industry. Determining the specifications for integrated professional curricula requires that a clear distinction be made between the differences of traditional research-based graduate education for academic scientific research and that of practice-based professional graduate education for technology development and engineering leadership of systematic innovation in industry. We believe that the characteristics that differentiate these two types of graduate studies can be distinguished best by using modern definitions of technology and engineering as they have evolved in the 21st century. These definitions are as follows:

- "As a creative profession, engineering is concerned with the combining of human, material, and economic resources to meet the needs of society for the advancement and betterment of human welfare. Engineering has a mission, purpose, and method. As creative professionals, engineers and technologists create, design, and lead the purposeful systematic development of new innovative technology in the form of new and improved products, processes, systems, operations, and breakthrough technological innovations responsive to real-world needs. And, in this process, they use the integrative method of engineering as a purposeful and systematic practice for innovation, entrepreneurship, and responsible leadership driven by an innovation ethic for improvement and betterment responsive to real-world needs."

  "However, whereas directed strategic scientific research is often necessary to gain a better understanding of physical phenomena during the systematic technology, development process, scientific research is not the primary driver. Creative engineering practice requires proactive, responsible leadership beginning with the identification of meaningful real-world needs. During the purposeful, creative technology development process, however, engineers and technology leaders must anticipate the need for directed strategic scientific research and know when and how to integrate the scientific research activity, when necessary, for effective technology development."

  National Collaborative Task Force
  ASEE- Graduate Studies Division-2003

- "Engineering is not science or even just "applied science." Whereas science is analytic in that it strives to understand nature, or what *is*, engineering is synthetic in that it strives to *create*. Our own favorite description of what engineers do is "design under constraint." Engineering is creativity constrained by nature, by cost, by concerns of safety, environmental impact, ergonomics, reliability, manufacturability, maintainability … To be sure our understanding of nature is one of the constraints we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one."[4]

  William A. Wulf, president
  National Academy of Engineering
  George M.C. Fisher, chairman
  National Academy of Engineering Council
  Retired chairman and CEO, Eastman Kodak Co.

- "In its broadest sense, technology is the process by which humans modify nature to meet their needs and wants. However, most people think of technology only in terms of its artifacts … But technology is more than its tangible products. An equally important aspect of technology is the knowledge and processes necessary to create and operate those products, such as engineering know-how and design, manufacturing expertise, various technical skills, and so on. Technology also includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts from corporate headquarters and engineering schools to manufacturing plants and maintenance facilities."[5]

Committee on Technology Literacy-2002
National Academy of Engineering

1.3 What Do Engineers Do?

As Fred Gary, former vice president of corporate engineering and manufacturing at General Electric Company, pointed out: "Development is the primary task of engineers" … and … "Great engineering is measured by the proper gauging of people's needs and the delivery of affordable, high-grade products and services."[6] But the development of technology is quite different from the pursuit of scientific research. As Martino, formerly of the Air Force Office of Scientific Research, has pointed out:

- "The term "research" is defined here as an attempt to acquire new knowledge about some phenomenon in the universe, or about some phenomenon in an abstract model of a portion of the universe, which is not necessarily made with an application in mind. The definition makes no distinction between basic and applied research, since the difference between the two terms is usually in the motivation of the researcher."

- "There is, however, a meaningful distinction between research and development: development is an attempt to construct, assemble, or prepare for the first time, a device, material, technique, or procedure, meeting a prescribe set of specifications or desired characteristics and intended to solve a specific problem. This definition includes not only mechanical devices and hardware, but such things as computer programs, chemicals, and other materials. The essence of this definition is that development is intended to meet some set of specifications in order to solve a specific problem … Research and development are two entirely different categories of activity, and there is no neat linear progression from one into the other … The kindest thing one can say for the (linear) model is that it is erroneous."[7]

2. Correlating Professional Graduate Education with the Process of Engineering for Systematic Technological Innovation

If the United States is to remain a world-leader in the new economy, then the urgency for reform of U.S. engineering and technology graduate education becomes increasingly critical as other nations are already improving their national innovation systems for competitiveness. Whereas in the past primary emphasis has been placed upon research-based graduate education for the nation's future academic researchers and teachers, equal emphasis must be place today on strengthening the nation's graduate engineering workforce who are responsible for leading the technology development and innovation process in industry for competitiveness But engineering education must change to meet this challenge.

2.1 Competency Gaps

In order to compete, U.S. engineering and technology education should be viewed in a broader sense than ever before. No longer can the United States afford to view engineering and technology education as limited to the undergraduate level or to the misperception that engineering is a byproduct of research. The career paths for the development of technology and the pursuit of scientific research are different. And graduate education in engineering and technology must reflect this difference, because one type of graduate education doesn't fit all purposes or all missions. Appendix I reflects the comparison of career paths in engineering and research.

If we are to unlock the creative, innovative, and leadership talent of our domestic engineering workforce, then we must take purposeful action to better develop the nation's higher educational infrastructure to better support what engineers and technologists do and are responsible for doing in industry and government service to sustain constant technological innovation. During the last decade there has been substantial criticism from industry and academia itself concerning several "competency gaps" that newly hired engineering graduates seem to exhibit relevant to the ability to actually practice creative engineering to meet real-world needs. Much of this criticism concerning the characteristics and skill-sets that we desire in experienced engineers and technologists is well deserved.

The criticisms cover the gamut and identification of critical professional gaps from business knowledge/skills; interpersonal skills; project management; written communication; oral communication/listening; international perspective; product/process design; open-ended problem solving through higher order multidisciplinary and systems thinking, as if undergraduate engineering and technology education can develop all of these skills within a four-year curriculum. There is no doubt that undergraduate education can begin to develop many of these critical skill-sets for engineering practice and technology leadership. However, as Spitzer has pointed out, It never has been possible to teach bachelor's level individuals everything they will ever need to know — although the educational system has behaved for many years as if this were a possible achievement. And as Cranch, former Dean of Engineering at Cornell, pointed out:

> "Much of the attention given to graduate study in engineering has focused on doctoral research, with the master's degree viewed as merely a steppingstone on the path to the Ph.D. … This emphasis on research is largely patterned after the physical sciences, where the traditional goal has been scholarly research … But a career in engineering is different from a career in the sciences … As the industrial revolution pushes wider and deeper into almost all realms of human activity, it is bringing about a marked change in the work force, with a growing number of functions requiring a substantial level of skill and sophistication … These changes mean increased educational requirements in all fields of engineering … The volume of material that must be taught is so great that it simply cannot be accommodated within the traditional four-year undergraduate curriculum … It is important to recognized that professional goals change during the course of an engineer's career. As engineers get older, many assume management responsibilities or enter a more multidisciplinary environment … From a curricular perspective, multidisciplinary work requires a knowledge base and maturity that is almost impossible to create at the bachelor's level."[8]

2.2 Skill Development Structure and Ownership

Recognition of engineering skill areas within government and industry creates an understanding of detailed ownership.[9] Today's engineering leaders often oversee functional areas with common skill sets. Creating a climate that ensures effective business driven learning and continuous development becomes a critical role element. These leaders, or skill owners, assume ownership for development of a particular skill area with the inherent accountability to ensure the ongoing existence of capability (or access to that capability) necessary to support current and future programs and initiatives. These skill owners acknowledge the variation within each skill area and accept responsibility to strengthen the skill area by strengthening individual members. How can this be accomplished? Creation of professional standards for each skill area containing unique as well as common skill sets. Common skill-set tools include communication, requirement setting, and problem solving.

These skill sets are named according to an agreed upon area of professional practice. A strong example is posted at the Randolph Air Force Personnel Center Directorate of Civilian Career Management website located at http://www.afpc.randolph.af.mil/cp/default.htm. Skill areas are coded according to the specific work accomplished at the detail level. This detail examination enhances competency requirement analysis. Within both government and industry, the competency gaps are routinely examined and development plans created to address current and future requirements. Often, plans are developed and implemented using non-traditional methods, such as internal training and / or specialized external training provided by private vendors rather than relying on traditional academia to provide solutions.

3. Defining the Tasks and Responsibilities of Engineering and Corporate Technology Leadership: From Exploratory Development Through Advanced Technology Development for Continual Improvement and Breakthrough Innovation of Products, Processes, Systems, and Operations

Today, engineering leadership is practiced in industry/government service through a spectrum of several professional levels beyond entry level. Appendixes II – IV reflect this spectrum. Accordingly, engineering and technology graduate education must be reshaped to foster growth through all leadership levels of engineering practice if the nation is to regain its competitive edge. Whereas at the undergraduate level emphasis in engineering and technology education is primarily focused on "design" as the essential characteristic that differentiates an engineering education from that of a scientific education, at the postgraduate level emphasis must become broader in context and focus on broader critical skill-sets and knowledge that are required for systematic development and responsible leadership of complex technological systems.

3.1 Assessing the Critical Skill-Sets, Knowledge, and Experience Levels Required In Engineering Practice for Leadership of Technology Development and Innovation

Today, most of the nation's engineers and technologists practice engineering and technology leadership throughout their careers at advanced leadership levels of practice. However, with notable exceptions, engineering and technology graduate education has not supported their growth or reflected the design of coherent curricula as a system for lifelong learning that enables professional growth of the nation's engineers and technologists through all levels of leadership. This has been a contributing factor to loss of the nation's competitiveness. To correct this education deficiency and major gap in the human resource development of U.S. technological strength, the National Collaborative Task Force believes that the identification of these higher responsibilities and skill-sets serve as the conceptual basis to formulate a coherent spectrum of high-quality postgraduate education as an integrated system for lifelong learning that enables further growth within the profession beyond entry level. To meet this challenge, the National Collaborative Task Force has taken the first step in reform by identifying the critical skill-sets, knowledge, and progressive experience required for all nine levels of engineering practice for leadership of technology development and innovation. Appendix V reflects the critical skill-sets, knowledge, and experience requirements as a total spectrum. The career profiles, professional characteristics, qualification standards, and skill-sets in engineering and technology leadership have been compiled from the National Academy of Engineering, National Society for Professional Engineers, industrial sources, and government agencies.[10,11,12,13,14,15,16]

3.2 Educating Engineers as Creative Professionals and Leaders of Technology: From Novice to Expert for Continuous Systematic Technology Development and Innovation

Because the process of engineering for purposeful technology development and innovation has changed, there is growing national awareness that U.S. engineering education itself must change from one focused primarily upon the transmission and acquisition of knowledge — from teacher to student — to one focused on the lifelong learning, growth, and development of creative professionals. In this process, it is now understood that engineers and technologists in industry/government service not only use existing knowledge, when applicable, but they also go beyond the equations as self-directed learners, experimenters, and creative knowledge workers through their own creative work and that they ultimately create new technological knowledge as a result of this systematic practice for purposeful innovation. A new educational approach is required at the postgraduate level that must include not only the transmission and acquisition of knowledge but also the development of intrinsic creative and leadership potential of the nation's engineers and technology leaders which correlates with and supports how engineers and technologists grow as creative technology leaders — from novice to expert — in meaningful creative technology development and innovation endeavors.

4. Conclusion

The challenge that faces U.S. engineering education today is the need for transformation to better develop the nation's creative engineering talent for competitiveness. Urgency for transformation exists in both undergraduate education and in graduate education. At the undergraduate level, urgency exists to better recruit the nation's domestic creative talent and to better prepare this talent for entry into engineering practice. At the professional-graduate level, urgency exists not only to better retain this creative talent but also to better develop this talent (beyond entry skills) within the U.S. engineering workforce to enhance U.S. innovative capacity. Transformation at the graduate level requires new university engagement with industry to better correlate professional graduate education with the needs of working professionals. The National Collaborative Task Force has initiated the second milestone for this transformation. The paper has assessed the stages of growth and the qualification standards that are required for progressive leadership responsibility in engineering practice. The qualification standards are based on the skill-sets, tasks, responsibilities, and roles of engineering (already established in industry and government service) from entry-level through senior executive levels of top corporate technology leadership. These standards will serve as a prescribed set of specifications for curricular design of high-quality, innovative professional graduate education that is more relevant to what engineers/technologists do and how they grow throughout their productive careers in creative engineering practice and leadership of systematic technological innovation in industry or government service.

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Appendix I

A Comparison Between Career Paths that Support Academic Research at Universities and those that Support Engineering Practice for Innovative Technology Development in Industry and Government Service

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Industry/Government (Technology Development)	**Universities (Academic Research)**
Senior Executive Levels	Senior Executive Levels
Engineer IX (GS-18, 17,16) Vice President of Engineering and Technology	Dean of Engineering/Technology
Executive Engineer Levels - Technology Leadership	Administrative Academic Levels
Engineer VIII (GS-15) Director of Engineering	Department Head
Engineer VII (GS-14) Department/Division Manager	Distinguished Professor
Engineer VI (GS-13) Technical Area Manager	Professor
Senior Engineer/Project Management Levels	Senior Research Specialist Levels
Engineer V (GS-12) Senior/Principal Engineer/Project Leader/Group Leader	Associate Professor
Engineer IV (GS-11) Project Engineer/Process Engineer	Assistant Professor (PhD)
Engineer III (GS-9) Design/Development Engineer	Post-Doctorate in Research
Entry Level in Engineering Practice	Entry Level in Academic Research
Engineer II/I (GS-7, 5) Entry Level Engineer/Engineer-in-Training	Graduate Research Assistant

Appendix II

Levels of Professional Responsibility for Leadership of Technology Development and Innovation in Industry and Government Service

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Top Levels of Technology Leadership

Position Title:

Engineer IX (GS-18, 17,16)
Vice President of Engineering and Technology

Engineer VIII (GS-15)
Director of Engineering

Middle Levels of Technology Leadership

Position Titles:

Engineer VII (GS-14)
Department/Division Manager

Engineer VI (GS-13)
Technical Area Manager

First Levels of Technology Leadership

Position Titles:

Engineer V (GS-12)
Senior Engineer/Principal Engineer/Project Leader/Group Leader

Engineer IV (GS-11)
Project Engineer/Process Engineer

Engineer III (GS-9)
Design/Development Engineer

Entry Level Engineer

Position Titles:

Engineer II/I (GS-7, 5)
Entry Level Engineer/Engineer-in-Training

Appendix III

Professional Characteristics, Leadership Responsibilities, And Growth Levels in Engineering Practice - NSPE

Engineer IX

Equivalent Federal General Schedule Grade
Senior Executive Service GS - 18, 17, 16

General Characteristics. An engineer in this level is either: 1) in charge of programs so extensive and complex as to require staff and resources of sizable magnitude (e.g., research and development, a department of government responsible for extensive engineering programs, or the major components of an organization responsible for the engineering required to meet the objectives of the organization); or 2) is an individual researcher or consultant who is recognized as a national and/or international authority and leader in an area of engineering or scientific interest and investigation.

Typical Position Titles. Director of Engineering, General Manager, Vice President, President, Partner, Dean, Director of Public Works

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks

Engineer VIII

Equivalent Federal General Schedule Grade
GS-15

General Characteristics. Make decisions and recommendations that are recognized as authoritative and have a far-reaching impact on extensive engineering and related activities of the company. Negotiates critical and controversial issues with top-level engineers and officers of other organizations and companies. Individuals at this level demonstrate a high degree of creativity, foresight, and mature judgment in planning, organizing and guiding extensive engineering programs and activities of outstanding novelty and importance.

Direction Received. Receives general administrative direction

Typical Duties & Responsibilities. One or both of the following: 1) In a supervisory capacity is responsible for a) an important segment of a very extensive and highly diversified engineering program, or b) the entire engineering program when the program is of moderate scope. The programs are of such complexity that they are of critical importance to overall objectives, include problems of extraordinary difficulty that often have resisted solution and consist of several segments requiring subordinate supervisors. Is responsible for deciding the kind and extent of engineering and related programs needed for accomplishing the objectives of the organization, for choosing the scientific approaches, for planning and organizing facilities and programs, and for interpreting results; 2) As individual researcher and consultant, formulates and guides the attack on problems of exceptional difficulty and marked importance to the organization or industry. Problems are characterized by their lack of scientific precedents and source material, or lack of success of prior research and analysis so that their solution would represent an advance of great significance and importance. Performs advisory and consulting work for the organization as a recognized authority for broad program areas or in an intensely specialized area of considerable novelty and importance.

Responsibility For Direction of Others. Supervises several subordinate supervisors or team leaders, some of whose positions are comparable to Engineer VII, or individual researchers some who whose positions are comparable to Engineer VII. As an individual researcher and consultant may be assisted on individual projects with other engineers and technicians.

Typical Position Titles. Chief Engineer, Bureau Engineer, Director of Research, Department Head or Dean, County Engineer, City Engineer, Director of Public Works, Senior Fellow, Senior Staff, Senior Advisor, Senior Consultant, Engineering Manager.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks

Engineer VII

Equivalent Federal General Schedule Grade
GS-14

General Characteristics. Make decisions and recommendations that are recognized as authoritative and have an important impact on extensive engineering activities. Initiates and maintains extensive contacts with key engineers and officials of other organizations and companies, requiring skill in persuasion and negotiation of critical issues. At this level individuals will have demonstrated creativity, foresight, and mature engineering judgment in anticipating and solving unprecedented engineering problems, determining program objectives and requirements, organizing programs and projects, and developing standards and guides for diverse engineering activities.

Direction Received. Supervision received is essentially administrative with assignments given in terms of broad general objectives and limits.

Typical Duties & Responsibilities. One or both of the following: 1) in a supervisory capacity is responsible for a) an important segment of the engineering program of an organization with extensive and diversified engineering requirements, or b) the entire engineering program of an organization when it is more limited in scope. The overall engineering program contains critical problems the solution of which requires major technological advances and opens the way for extensive related development. The extent of responsibilities generally requires several subordinate organizational segments or teams. Recommends facilities, personnel, and funds required to carry out programs which are directly related with and directed toward fulfillment of overall organization objectives; 2) As individual researcher and consultant is a recognized leader and authority in the organization in a broad area of specialization or in a narrow but intensely specialized field. Selects research problems to further the organization's objectives. Conceives and plans investigations of broad areas of considerable novelty and importance for which engineering precedents are lacking in areas critical to the overall engineering program. Is consulted extensively by associates and others with a high degree of reliance placed on the scientific interpretations and advice. Typically, will have contributed inventions, new designs, or techniques which are regarded as major advances in the field.

Responsibility For Direction of Others. Directs several subordinate supervisors or team leaders, some of whom are in a position comparable to Engineer VI, or as individual researcher and consultant, may be assisted on individual projects by other engineers and technicians.

Typical Position Titles. Principal Engineer, Division or District Engineer, Department Manager, Director or Assistant Director of Research, Consultant, professor, Distinguished Professor or Department Head, Assistant Chief or Chief Engineer, City or County Engineer.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status, Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks

Engineer VI

Equivalent Federal General Schedule Grade
GS-13

General Characteristics. Has full technical responsibility for interpreting, organizing, executing, and coordinating assignments. Plans and develops engineering projects concerned with unique or controversial problems which have an important effect on major organization programs. This involves exploration of subject area, definition of scope and selection of problems for investigation and development of novel concepts and approaches. Maintains Liaison with individuals and units within or outside the organization with responsibility for acting independently on technical matters pertaining to the field. Work at this level usually requires extensive progressive experience.

Direction Received. Supervision received is essentially administrative, with assignments given in terms of broad general objectives and limits.

Typical Duties & Responsibilities. One or more of the following: 1) in a supervisory capacity a) plans, develops, coordinates, and directs a number of large and important projects or a project of major scope and importance; or b) is responsible for the entire engineering program of an organization when the program is of limited complexity and scope. The extent of his or her responsibilities generally requires a few (3 to 5) subordinate supervisors or team leaders with at least one in a position comparable to level V; 2) As individual researcher or worker conceives, plans and conducts research in problem areas of considerable scope and complexity. The problems must be approached through a series of complete and conceptually related studies, are difficult to define, require unconventional or novel approaches, and require sophisticated research techniques. Available guides and precedents contain critical gaps, are only partially related to the problem or may be largely lacking due to the novel character of the project. At this level, the individual researcher generally will have contributed inventions, new designs, or techniques which are of material significance in the solution of important problems; 3) As a staff specialist serves as the technical specialist for the organization (division or company) in the application of advanced theories, concepts, principles, and processes for an assigned area of responsibility (i.e. subject matter, function, type of facility or equipment, or product). Keeps abreast of new scientific methods and developments affecting the organization for the purpose of recommending changes in emphasis of programs or new programs warranted by such developments.

Responsibility For Direction of Others. Plans, organizes, and supervises the work of a staff of engineers and technicians. Evaluates progress of the staff and results obtained and recommend major changes to achieve overall objectives. Or, as individual research or staff specialist may be assisted on individual projects by other engineers or technicians.

Typical Position Titles. Senior or Principal Engineer, Division or District Engineer, Production Engineer, Assistant Division, District or Chief Engineer, Consultant, Professor, City or County Engineer.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade).Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks

Engineer V

Equivalent Federal General Schedule Grade
GS-12

General Characteristics. Applies intensive and diversified knowledge of engineering principles and practices in broad areas of assignments and related fields. Make decisions independently on engineering problems and methods, and represents the organization in conferences to resolve important questions and to plan and coordinate work. Requires the use of advanced techniques and the modifications and extension of theories, precepts and practices of the field and related sciences and disciplines. The knowledge and expertise required for this level of work usually result from progressive experience.

Direction Received. Supervision and guidance relate largely to overall objectives, critical issues, new concepts, and policy matters. Consults with supervisor concerning unusual problems and developments.

Typical Duties & Responsibilities. One or more of the following: 1) In a supervisory capacity, plans, develops, coordinates, and directs a large and important engineering project or a number of a small projects with many complex features. A substantial portion of the work supervised is comparable to that described for engineer IV; 2) As individual researcher or worker, 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 improved techniques and procedures. Work is expected to result in the development of new or refined equipment, materials, processes, products, and/or scientific methods; 3) As staff specialist, develops and evaluates plans and criteria for a variety of projects and activities to be carried out by others. Assesses the feasibility and soundness of proposed engineering evaluation tests, products, or equipment when necessary data are insufficient or confirmation by testing is advisable. Usually performs as a staff advisor and consultant as to a technical specialty, a type of facility or equipment, or a program function.

Responsibility For Direction of Others. Supervises, coordinates, and reviews the work of a small staff of engineers and technicians, estimates personnel needs and schedules and assigns work to meet completion date. Or, as individual researcher or staff specialist may be assisted on projects by other engineers or technicians.

Typical Position Titles. Senior or Principal Engineer: Resident, Project, Office, Design, Process, Research, Ass't Division Engineer, Associate Professor, Project Leader.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks

Engineer IV

Equivalent Federal General Schedule Grade
GS-11

General Characteristics. As a fully competent engineer in all conventional aspects of the subject matter of the functional area of the assignments, plans and conducts work requiring judgment in the independent evaluation, selection, and substantial adaptation and modification of standard techniques, procedures, and criteria. Devises new approaches to problems encountered. Requires sufficient professional experience to assure competence as a fully trained worker, or, for positions primarily of a research nature, completion of all requirements for a doctoral degree may be substituted for experience.

Direction Received. Independently performs most assignments with instructions as to the general results expected. Receives technical guidance on unusual or complex problems and supervisory approval on proposed plans for projects.

Typical Duties & Responsibilities. Plans, schedules, conducts, or coordinates detailed phases of the engineering work in a part of a major project or in a total project of moderate scope. Performs work which involves conventional engineering practice but may include a variety of complex features such as conflicting design requirements, unsuitability of conventional materials, and difficult coordination requirements. Work requires a broad knowledge of precedents in the specialty area and a good knowledge of and practices of related specialties.

Responsibility For Direction of Others. May supervise or coordinate the work of engineers, drafters, technicians, and others who assist in specific assignments.

Typical Position Titles. Engineer or Assistant Engineer, Resident, Project, Plant, Office, Design, Process, Research, Chief Inspector, Assistant Professor.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade),Member of Technical Societies (Associate Grade or Equivalent)/Member of Technical Societies (Member Grade); Publishes engineering papers, articles, text books

Engineer III

Equivalent Federal General Schedule Grade
GS-9

General Characteristics. Independently evaluates, selects, and applies standard engineering techniques, procedures, and criteria, using judgment in making minor adaptations and modifications. Assignments have clear and specified objectives and require the investigation of a limited number of variables. Performance at this level requires developmental experience in a professional position or equivalent graduate level education.

Direction Received. Receives instructions on specific assignment objectives, complex features, and possible solutions. Assistance is furnished on unusual problems and work is reviewed for application of sound professional judgment.

Typical Duties & Responsibilities. Performs work which involves conventional types of plans, investigations, surveys, structures, or equipment with relatively few complex features for which there are precedents. Assignments usually include one or more of the following: Equipment design and development, test of materials, preparation of specifications, process study, research investigations, report preparation, and other activities of limited scope requiring knowledge of principles and techniques commonly employed in the specific narrow area of assignments.

Responsibility For Direction of Others. May supervise or coordinate the work of drafters, technicians, and others who assist in specific assignments.

Typical Position Titles. Engineer or Assistant Engineer, Project, Plant, Office, Design, Process, Research Chief Inspector, Assistant Professor

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Certified Engineer Intern/Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Associate Grade/Member Grade), Member of Technical Societies (Associate Grade or Equivalent)

Engineer I/II

Equivalent Federal General Schedule Grade
GS- 5, 7

General Characteristics. This is the entry level for professional work. Performs assignments designed to develop professional works knowledge and abilities, requiring application of standard techniques, procedures, and criteria in carrying out a sequence of related engineering tasks. Limited exercise of judgment is required on details of work and in making preliminary selections and adaptations of engineering alternatives.

Direction Received. Supervisor screens assignments for unusual or difficult problems and selects techniques and procedures to be applied on nonroutine work. Receives close supervision on new aspects of assignments.

Typical Duties & Responsibilities. Using prescribed methods, performs specific and limited portions of a broader assignment of an experienced engineer. Applies standard practices and techniques in specific situations, adjusts and correlates data, recognizes discrepancies in results, and follows operations through a series of related detailed steps or processes.

Responsibility For Direction of Others. May be assisted by a few aides or technicians.

Typical Position Titles. Junior Engineer, Associate Detail Engineer, Engineer-in-Training, Ass't Research Engineer, Construction Inspector.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Certified Engineer Intern/Engineering-In-Training

Typical Professional Attainments. Member of Professional Society (Associate Grade), Member of Technical Societies (Associate Grade or Equivalent)

Appendix IV

Stages of Growth and Levels of Responsibility for Leadership of Technology Development and Innovation in Industry and Government Service

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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 principle and techniques commonly employed in the specific narrow areas of assignments.
ENGINEER I/II (Entry Level)	Requires knowledge and application of known laws and data. Using prescribed methods, applies standard practices/techniques under direction of an experienced Engineer.

Appendix V

Levels of Critical Skill-Sets, Knowledge, and Experience Required in Engineering Practice for Leadership of Technology Development And Innovation in Industry and Government Service

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Core Qualifications - Senior Executive Engineer Levels

Top Levels of Corporate Technology Leadership

Engineers at the top levels of corporate technology leadership act in responsible charge for defining the core character, mission, vision, goals, and objectives of the technology-based organization; for setting responsible technology policy; for building an organizational culture that fosters a core value system of ethical responsibility; for planning, staffing, organizing, and allocating financial, professional, and material resources to enhance the organization's overall technological thrust; and for building an innovative culture that continually fosters the organization's core competence and innovative capacity for constant technology development and innovation such that industrial creativity and innovation can flourish to sustain the organization's competitive advantage responsive to customer needs.

Engineer IX (GS-18,17,16) 20+ years of progressive experience
Vice President of Engineering and Technology

Critical Skills-Sets, Knowledge, and Experience Required as Defined by Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Broad overall knowledge of corporate systems technology
- External awareness of competitive technology
- Strategic vision
- Leading change
- Leading people
- Results driven
- Business acumen
- Building coalitions/communications
- Technology policy making
- Ethical value judgment
- Integrity

Core Qualifications - Executive Engineer Levels

Third Level of Technology Leadership

Engineers at the third level of corporate technology leadership act in responsible charge for defining, planning, organizing, integrating, and leading the overall technological development of new or improved large scale/complex programs, systems, or operations responsive to corporate objectives, goals, vision and mission of the technology-based organization.

Engineer VIII (GS-15) 20+ years of progressive experience
Director of Engineering

Engineer VII (GS-14) 15+ years of progressive experience
Department/Division Manager

Critical Skills-Sets, Knowledge, and Experience Required as Defined by
Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Expert knowledge of corporate systems technology
- Broad understanding of emerging sciences relevant to organization's technological thrust
- Leading major systems engineering and cross functional teams
- Financial management/understanding of the economics of technology development and innovation
- Human resources management and development of engineering profession
- Organizational development of innovative cultures for technology development
- Corporate decision analysis/decision making for innovative technology programs
- Value judgment and ethical decision-making regarding safety issues, environmental issues, understanding systems failures, and prevention
- Mentoring of creative professionals for future leadership positions

Core Qualifications - Senior Engineer/Project Management Levels

Second Level of Technology Leadership

Engineers at the second level of corporate technology leadership act in responsible charge for defining, planning, organizing, integrating, and leading the development and innovation of large-scale complex programs within functional technological areas.

Engineer VI (GS-13) 12+ years of progressive experience
Functional Area Manager

Engineer V (GS-12) 9+ years of progressive experience
Senior Engineer/Principal Engineer/Project Leader/Group Leader

Critical Skills-Sets, Knowledge, and Experience Required as Defined by
Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Expert knowledge of functional area technology
- Core systems engineering and multidisciplinary thinking with responsible charge
- Needs-finding and identification of problems/opportunities for technology program-making
- Innovative thinking and strategic vision for program development planning from phases of conceptual exploratory development through advanced engineering development, and recognizing the need for directed research to gain a better understanding of anticipated or unknown phenomenon during technology development programs
- Contracting processes and regulations
- Project leadership and tracking
- Teambuilding
- Coaching of creative professionals
- Customer orientation

- Quality focus

Core Qualifications – Project Engineer Levels

First Levels of Technology Leadership

Engineers at the first levels of corporate technology leadership are fully competent engineering professionals and act in responsible charge for development and innovation of new or improved components of a subsystem or project.

Engineer IV (GS-11) 7+ years of progressive experience
Project Engineer/Process Engineer

Engineer III (GS-9) 5+ years of progressive experience
Design/Development Engineer

Critical Skills-Sets, Knowledge, and Experience Required as Defined by
Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Expert knowledge of core project technology/process technology/product technology
- Competency in engineering method for systematic technology development and innovation
- Creative problem solving for innovative solutions to open-ended problems/opportunities
- Ethical judgment relevant to safety issues and environmental issues
- Engineering-technical judgment
- Project engineering
- Communication
- Critical thinking
- Self-directed learning

Core Qualifications - Entry Level Engineer

Entry – Trainee Level

Engineers at the entry-level of technology responsibility work at the level of known laws and data under close supervision of an experienced engineer on specific and limited portions of a broader assignment using prescribed methods, standard techniques, and procedures.

Engineer I/II (GS-5,7)
Entry Level Engineer/Engineer-in-Training

Critical Skills-Sets, Knowledge, and Experience Required as Defined by
Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Graduate of ABET approved program in engineering or technology
- Initiative, enthusiasm, ability to work well with others, and high growth potential for technology development and leadership of innovation in industry
- Attainment of ABET requirements at the basic educational level for entry into engineering practice

  a) an ability to apply knowledge of mathematics, science, and engineering
  b) an ability to design and conduct experiments, as well as to analyze and interpret data

c) an ability to design a system, component, or process to meet desired needs
d) an ability to function on multi-disciplinary teams
e) an ability to identify, formulate, and solve engineering problems
f) an understanding of professional and ethical responsibility
g) an ability to communicate effectively
h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
i) a recognition of the need for, and an ability to engage in lifelong learning
j) a knowledge of contemporary issues
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.