

AC 2009-623: STRENGTHENING THE U.S. ENGINEERING WORKFORCE FOR TECHNOLOGY INNOVATION: PROFESSIONAL GRADUATE ENGINEERING EDUCATION THAT SUPPORTS THE METHOD ENGINEERS USE TO CREATE, DEVELOP, AND INNOVATE NEW TECHNOLOGY

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Strengthening the U.S. Engineering Workforce for Technology Innovation: Professional Graduate Engineering Education that Supports the Method Engineers Use to Create, Develop, and Innovate New Technology

1. Introduction

The National Collaborative is creating and implementing a new model for professional graduate engineering education that enables continued growth of graduate engineers in industry and government service throughout their entire professional careers — from entry-level through the highest levels of professional engineering leadership for innovation and creative practice. This model reflects the manner by which practicing engineers recognize real-world needs, understand the issues involved, learn the existing state-of-the art of technology through self-directed and experiential learning, identify and formulate realistic specifications required for effective solution, direct scientific research efforts to gain a better understanding of phenomena involved, and actually create, develop, and innovate new ‘ideas’ from conceptual exploratory stages of development through the later stages of systems operational development is put forth. The model is patterned after actual engineering development programs and experience in aerospace and other industrial practice. The primary focus of this advanced professional educational model in engineering is to support the professional growth of the graduate engineer through action-learning by working on real issues that lead to effective action and innovation in the practitioner’s industry.

The framework for this new model of professional engineering education has been presented previously; most recently at the ASEE National meeting in 2008.¹⁻⁷ It establishes three educational benchmarks for the practicing professional engineer; Early Career (Master of Engineering degree), Mid Career (Doctor of Engineering degree), and Senior Career (Engineering Fellow degree). The centerpiece of this model is its focus on technology development projects. These are projects of significance to the engineer’s company and are expected to be either part of or an extension of his or her assigned tasks. This paper will discuss the way these projects foster a synergism between innovative technology development and the professional growth of the practicing professional engineer in this educational model and how they might vary with the educational level / professional development of the practicing professional engineer.

2. Innovative Technology Development and Engineering Practice

The professional engineer systematically applies the Engineering Method shown below to create technologies that satisfy real world needs.

Needs → Engineering → Technology

↑↓

Directed Scientific Research
to gain a better understanding
of phenomena when needed

It depicts the role that engineering and directed scientific research play in innovative technology development. However it does not illustrate the many and varied roles at all professional levels that engineers assume in engineering a technology.

The wide variety of engineering activities associated with technology development is perhaps better illustrated with a scale of technology readiness levels. Technology readiness levels are used by many industries as a metric for the evolution of technology development projects. A typical scale of technology readiness levels is shown in Figure 1. This, too, is a depiction of the Engineering Method viewed from a somewhat different perspective. But a technology readiness scale does not illustrate the different engineering roles played by practicing engineers at different levels of professional development.

3. Professional Education for Engineers for Innovative Technology Development

The National Society of Professional Engineers (NSPE) has identified nine stages of professional maturation, autonomy, and responsibility in engineering practice, from entry level to the highest levels of technology leadership. These are presented in Appendix A. The correlation between these nine levels and the educational milestones in framework for the new model for professional graduate engineering education are shown in Appendix B. Here we discuss in general terms the scope of the technology development project at each milestone.

3.1 Early Career – The Professional Master of Engineering

The Master of Engineering degree program is designed to enable the practicing professional engineer to grow from entry level to a position of project engineering leadership. The participant will develop the project management skills necessary to lead successful projects in his or her company. The participant will develop the skills necessary to successfully create and conduct successful technology development projects in his or her company.

The participant at this level is expected to satisfactorily complete a technology development / technology improvement project with the mentorship of mid career engineers from his or her company and core faculty from the program. This project will include needs finding, team building, profitability and economic justification, and performance metrics. It will culminate with a written and oral presentation of the project as a case study.

4.2 Mid Career – The Professional Doctor of Engineering

The Doctor of Engineering degree program is designed to enable the practicing professional engineer to grow from a position of successful engineering project leadership to position of successful technology program leadership. The participant should have a track record including several years of successful project leadership. The participant is expected to be a recognized expert in one or more of his or her company's technologies. As appropriate, the participant will keep abreast of cutting-edge changes in these and other technologies relevant to the company by participation in short courses, seminars and the like. The participant will develop the program management skills necessary to lead successful programs in his or her company. The participant will develop the skills create and conduct successful programs in his or her company.

The participant at this level is expected to initiate and conduct a successful a technology development program consisting of several technology development / technology improvement projects appropriate to his or her professional setting. This activity will be mentored by senior level engineers from the company and core faculty from the program. The participant will be expected to initiate and justify a technology development program to the mentors, gather together technology teams for its implementation, develop

metrics for its progress and success. The program will culminate with a written and oral presentation of the program as a case study.

4.3 Senior Career – The Professional Engineering Fellow Degree

The Engineering Fellow degree program is designed to enable the practicing professional engineer to grow from a position of successful engineering program leadership to a position of successful technology policy making. The participant should have a track record including several years of successful program leadership. The participant is expected to be knowledgeable in all relevant technologies not only in his or her company but also corporate competitors. As appropriate, the participant will keep abreast of cutting-edge changes in these technologies by participation in short courses, seminars and the like. The participant will develop the executive leadership skills necessary to assess technological trends and set technology policy that help his or her company either establish or maintain a position of strength in the global markets.

The participant at this level is expected to initiate and defend a technology policy position for his or her company. This activity will be mentored by engineers at the highest senior level the company and core faculty from the program. The participant will be expected to assess trends in technologies relevant to the company, make an assessment of the financial risks associated with the policy proposed, and present the technology policy to personnel at the highest decision-making levels of the company. The technology policy also will include a written and oral presentation as a case study.

5. Conclusions

The National Collaborative is creating and implementing a new model for professional graduate engineering education that enables continued growth of graduate engineers in industry and government service throughout their entire professional careers — from entry-level through the highest levels of professional engineering leadership for innovation and creative practice. The model is patterned after actual engineering development programs and experience in aerospace and other industrial practice. Consequently, the centerpiece of the model is the technology development project. Here we have discussed in general terms the way in which technology development projects form a key component of the program of advanced professional engineering education at each educational milestone from entry level to senior career level. Because the technology development projects are selected for their relevance to the engineer's company, they synergistically meld the professional development that is crucial to the success of the practicing engineer with the technology development that is crucial to success of his or her company.

References

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Appendix A

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

<u>Stages of Growth</u>	<u>Typical Responsibilities-Autonomy-Judgment</u>
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 Engineer)	Requires knowledge and application of known laws and data. Using prescribed methods, applies standard practices/techniques under direction of an experienced Engineer.

Appendix B

Levels of Responsibilities in Creative Engineering Practice for Engineering Leadership of Continuous Technology Development & Innovation In Industry and Government Service

Top Levels of Technology Leadership

Position Title:

Engineer IX (GS-18, 17, 16)
Chief Engineer / Vice President of Engineering & 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

Appendix C-1

Framework: For High-Quality Postgraduate Professional Education Leading to The Professional Master of Engineering that is Integrative with Practice and Enables Lifelong Learning and Professional Development of Engineers as Creative Professionals and Technology Leaders in Industry

Professional Master of Engineering – For Creative Engineering Practice & Leadership Level IV Engineer – Skill-Sets / Outcomes

**Focus: Professional Development of Emerging Engineer-Leaders in Industry
For Creative Technology Development & Innovation at Project Leadership Level**

Postgraduate Professional Education Integrative with Creative Engineering Practice

18 Credit Hours

Core Professional Courses

Emphasis on the professional dimensions / knowledge / critical skill-sets required in engineering practice (at Level IV Engineer) for engineering leadership, professional responsibility, and creative problem solving at project engineering level for technology development & innovation in industry/government service.

(Six Professional Courses)

6 Credit Hours

Professional Electives

Emphasis on flexibility in tailoring program electives to be relevant to the participant's field of technology/or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules.

(Two Elective Courses)

6 Credit Hours

Directed Technology Development Project

Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of meaningful significance that is directly relevant to the technology development & innovation needs of the participant's sponsoring industry. This work should represent innovative development at the project leadership level wherein the participant is in responsible charge.

30 Credit Hours

Appendix C-1

Integrative Components: For High-Quality Postgraduate Professional Education Leading to the Professional Master of Engineering with Practice and Enables Lifelong Learning and Professional Development of Engineers as Creative Professionals and Technology Leaders in Industry

Professional Master of Engineering – For Creative Engineering Practice & Leadership Level IV Engineer – Skill-Sets / Outcomes

Focus: Professional Development of Emerging Engineer-Leaders in Industry For Creative Technology Development & Innovation at Project Leadership Level

Integrative Components:

- **Curricular Components**

- 18 cr. Core Professional Modules
- 6 cr. Elective Modules
- 6 cr. Technology Development Project
In Industry (Focus on Innovation)

30 cr. Total

- **Professional Maturation Components**

- a) **Residency Component**

- Full-time employment in engineering practice in industry/government service

- b) **Progressive Experience Component Beyond Entry-Level**

- Minimum of 3 to 5 years of progressive experience beyond entry-level in engineering practice

- c) **Technical Competency Component**

- Demonstrated growth from novice to competent professional in a specific technological field

- **Admission Requirements to Program**

- Graduate of ABET program in engineering / or engineering technology; Minimum of at least 6 months beyond entry-level experience in engineering practice; Level II Engineer; plus strong letters of recommendation from participant's sponsor / practicing professionals in engineering; and FE when appropriate. The Graduate Record Examination is required by many programs across the country. Minimum scores are set by graduate schools and/or departments offering graduate degrees.

Appendix C-2

Framework: For High Quality Postgraduate Professional Education Leading to The Professional Doctor of Engineering that is Integrative with Practice and Enables Lifelong learning and Professional Development of Engineers as Creative Professionals and Technology Leaders in Industry

**Professional Doctor of Engineering – For Creative Engineering Practice & Leadership
Level VI Engineer - Skill-Sets / Outcomes**

**Focus: Professional Development of Experienced Engineer-Leaders in Industry
For Creative Technology Development and Innovation at Program Leadership Level**

Postgraduate Professional Education Integrative with Creative Engineering Practice

12 Credit Hours

Core Professional Courses

Emphasis on the professional dimensions / knowledge / critical skill-sets required in advanced engineering practice (Level VI Engineer) for engineering leadership, professional responsibility, and creative problem solving at technical program level for technology development and innovation in industry/government service.

(Four Professional Courses)

6 Credit Hours

Professional Electives

Emphasis on flexibility in tailoring the program electives to be relevant to the participant's field of technology or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules.

(Two Elective Courses)

12 Credit Hours

Directed Technology Development Project

Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of meaningful significance that is directly relevant to the technology development & innovation needs of the participant's sponsoring industry. This work should represent significant innovative development e.g. at the technical program leadership level wherein the participant is in responsible charge at (Level VI Engineer).

30 Credit Hours

Appendix C-2

Components: For High-Quality Postgraduate Professional Education Leading to The Professional Doctor of Engineering that are Integrative with Practice and Enable Lifelong learning and Professional Development of Engineers as Creative Professionals and Technology Leaders in Industry

**Professional Doctor of Engineering – For Creative Engineering Practice and Leadership
Level VI Engineer – Skill-Sets / Outcomes**

**Focus: Professional Development of Experienced Engineer-Leaders in Industry
For Creative Technology Development and Innovation at Program Leadership Level**

Integrative Components:

- **Curricular Components**

- 12 cr. Core Professional Modules
- 6 cr. Elective Modules
- 12 cr. Technology Development Project
In Industry (Focus on Innovation)

30 cr. Total

- **Professional Maturation Components**

- a) Residency Component
Full-time employment in engineering practice in industry/government service
- b) Progressive Experience Component Beyond Entry-Level
Minimum of ten years of progressive experience beyond entry-level in engineering practice
- c) Technical Competency Component
Demonstrated growth from competent professional to expert in a specific technological field

- **Admission Requirements to Program**

Holder of the professional Master of Engineering (M.Eng.) degree or equivalent; ten years of progressive experience in engineering practice beyond entry-level; Level IV Engineer; plus strong letters of recommendation from participant's sponsor / practicing professionals in engineering; and PE when appropriate.

Appendix C-3

Framework: For High-Quality Postgraduate Professional Education Leading to
The Professional Fellow of Engineering that is Integrative with Practice and
Enables Lifelong learning and Professional Development of Engineers
As Creative Professionals and Technology Leaders in Industry

**Professional Fellow of Engineering – For Creative Engineering Practice and Leadership
Level VIII Engineer - Skills-Sets / Outcomes**

**Focus: Professional Development of Senior Engineer-Leaders in Industry for
Creative Technology Development and Innovation at Technology Policy Leadership Level**

Postgraduate Professional Education Integrative with Creative Engineering Practice

- | | |
|------------------------|--|
| 6 Credit Hours | Advanced Professional Seminars/Courses
Emphasis on the professional dimensions / knowledge / critical skill-sets required in advanced engineering practice (Level VIII Engineer) at the levels of executive technology policymaking, strategic planning, and corporate engineering responsibility for the technological corporate thrust
(Two Professional Courses) |
| 6 Credit Hours | Professional Electives
Emphasis on flexibility in tailoring the program electives to be relevant to the participant's field of technology or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules.
(Two Elective Courses) |
| 18 Credit Hours | Directed Technology Development Project
Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of significant attainment that is directly relevant to the corporate leadership needs for technology development & innovation of the participant's sponsoring industry. This work should represent leadership of significant innovative technology development at the level of a white paper setting technology policy for the sponsoring organization e.g. at the technology leadership policy leadership level wherein the participant is in responsible charge at (Level VIII Engineer). |

30 Credit Hours

Appendix C-3

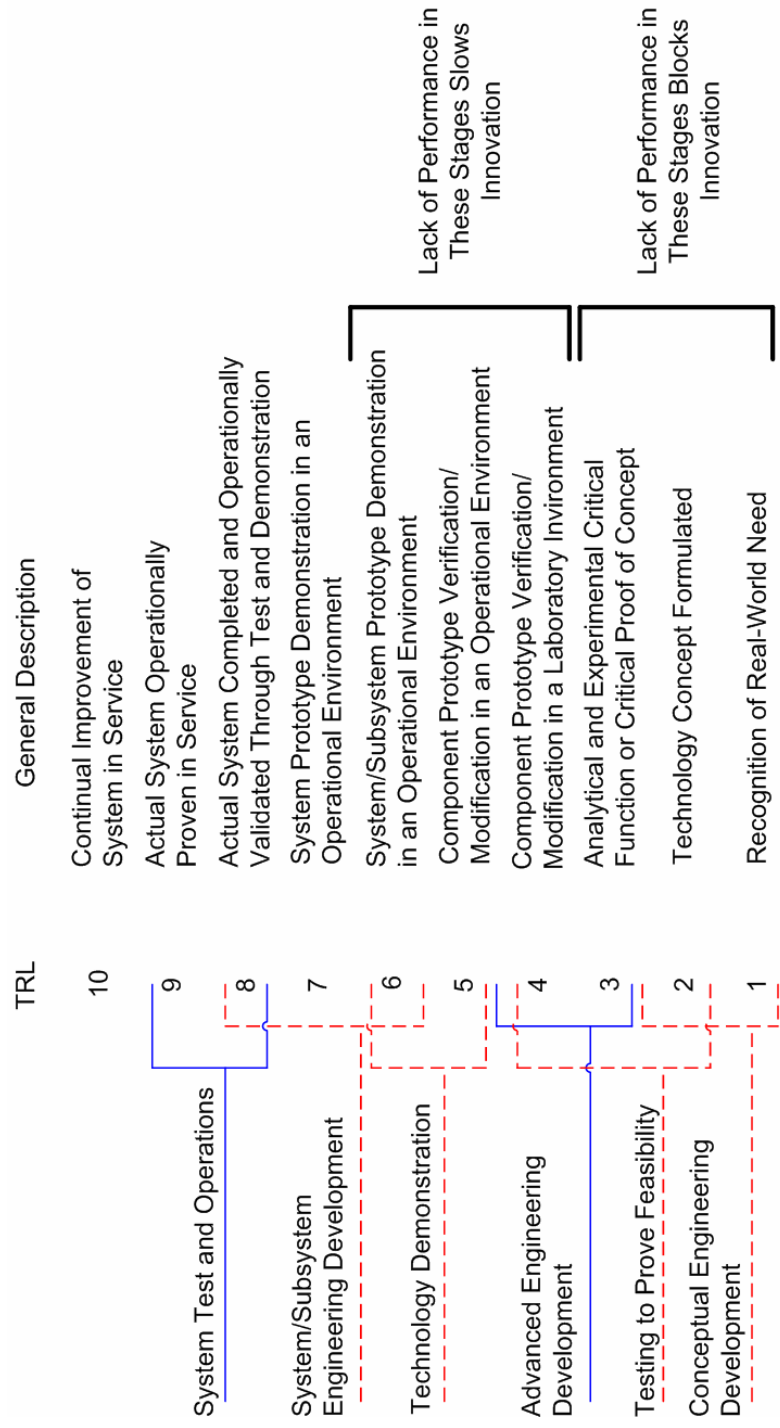
Components: For High-Quality Postgraduate Professional Education Leading to The Professional Fellow of Engineering that are Integrative with Practice and Enable Lifelong Learning and Professional Development of Engineers as Creative Professionals and Technology Leaders in Industry

**Professional Fellow of Engineering – For Creative Engineering Practice and Leadership
Level VIII Engineer – Skill-Sets / Outcomes**

**Focus: Professional Development of Senior Engineer-Leaders in Industry for
Creative Technology Development and Innovation at Technology Policy Leadership Level**

Integrative Components:

- Curricular Components
 - 6 cr. Core Professional Modules
 - 6 cr. Elective Modules
 - 18 cr. Technology Development Project
In Industry (Focus on Innovation)
 - _____
 - 30 cr. Total
- Professional Maturation Components
 - a) Residency Component
 - Full-time employment in engineering practice in industry/government service
 - b) Progressive Experience Component Beyond Entry-Level
 - Minimum of 15 years of progressive experience beyond entry-level in engineering practice
 - c) Technical Competency Component
 - Demonstrated growth from competent professional to expert in a specific technological field
- Admission Requirements to Program
 - Holder of the professional Doctor of Engineering (D.Eng.) degree or equivalent; fifteen years of progressive experience in engineering practice beyond entry-level; Level VIII Engineer; plus strong letters of recommendation from participant's sponsor / practicing professionals in engineering; and PE when appropriate.



TRL = Technology Readiness Level

Figure 1: Technology Readiness Levels in the Practice of Engineering for Technology Innovation