AC 2008-362: ENSURING A STRONG U.S. ENGINEERING WORKFORCE FOR TECHNOLOGY INNOVATION AND COMPETITIVENESS: THE FRAMEWORK OF PROFESSIONAL EDUCATION FOR INNOVATION

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Ensuring a Strong U.S. Engineering Workforce for Technology Innovation and Competitiveness: The Framework of Professional Education for Innovation

1. Introduction

Engineering education has been the focus of numerous papers and reports in the last several decades.[1-4] Almost without exception, the authors have called for changes in the way engineers are educated in a world of rapidly changing technology. Unfortunately, while the changes have that have resulted have focused on engineering education in the traditional academic context, the advanced professional education of practicing professional engineers has not received its due.[5] The National Collaborative Task Force was established to address this need. Its mission is to establish high-quality professional graduate engineering education centered on the modern practice of engineering and the engineering method for innovation that enables the further professional development of engineers in industry. The focus is to further the growth of the working professional in industry. The professional curricula is being designed as a matrix of studies integrative with engineering practice that match, support, and correlate with the modern paradigm of engineering practice and progression of professional abilities required for responsible leadership in engineering innovation from entry level engineer through chief engineer level responsibilities. The evolving model is centered around five major components: a) Relevant advanced studies; b) Self-directed learning; c) Experiential-learning; d) Project-based learning [advanced technology development project directly relevant to industry / socio need]; and e) On-going engagement in engineering practice for innovation and creative works. The process is centered around the known attributes of high-quality professional education already demonstrated across the United States that enable growth and positive development of working professionals [Council of Graduate Schools — Conrad Report[8]]: a) Cultures that support collaborative learning, creativity, and innovation; b) Planned studies with tangible outcomes; c) Learner centered education rather than teacher-centered instruction; d) Learning environment of core faculty of practitioner-scholars from the university, adjunct faculty of distinguished leaders from industry, a student body of experienced practitioners from regional industry.

2. What Professional Engineers Do – The Practice of Engineering

The US Department of Labor identifies approximately 2,500,000 practicing engineers in the United States.[10] These knowledge workers create most of the technologies that drive our economy. They are envied worldwide for there creativity and ingenuity. For the most part, they are employed in either industry or government service (85%) and they are involved primarily in creative technology development (72%) (See Figure 1). Engineering is a creative profession. The practice of engineering is not simply applied science. It is much more then design under constraint. The professional engineer systematically applies the Engineering Method shown below to create technologies that satisfy real world needs (See also Figure 2).

$$\begin{array}{c}\text{Needs} \rightarrow \text{Engineering} \rightarrow \text{Technology} \\ \uparrow\downarrow \\ \text{Directed Scientific Research} \\ \text{to gain a better understanding} \\ \text{of phenomena when needed}\end{array}$$

It is important to note here that need drives the engineering activity which results in new technologies, products, and processes. The National Collaborative Task Force has chosen to craft its program of advanced studies for professional engineers with a focus on this understanding of engineering practice.

3. How Professional Engineers Grow

Receipt of the baccalaureate in engineering represents the starting point of a career in industry or government practice for professional engineers. This degree provides one with a strong foundation in the sciences and mathematics. In addition, it provides one with an elementary understanding of the knowledge base associated with a particular engineering discipline. But as the engineer grows professionally throughout his or her career, new knowledge and new skills are required. The National Academy of Engineering (NAE) has identified some of the educational challenges that will be faced by the engineer of 2020.[3] Keeping in mind not only that the body of technological knowledge is expanding rapidly but also that the baccalaureate does adequately prepare the professional engineer for a lifetime of practice, it is evident that a program of lifelong professional education must be made available to the practicing engineer. The National Collaborative Task Force has addressed that need.

The National Society of Professional Engineers (NSPE) has identified nine stages of professional maturation, autonomy, and responsibility in engineering practice. These are presented in Appendices A and B. While job responsibilities and titles vary from institution to institution, the career-long growth of the practicing professional engineer follows these general guidelines. It is for this reason that the National Collaborative Task Force has chosen to use them to establish outcomes for the program of advanced professional engineering education.

4. Professional Education for Engineers

The baccalaureate has traditionally been recognized as the terminal degree of the practicing engineer. His or her post-baccalaureate education has consisted of coursework, sometimes with a thesis component, leading to either an MS or an MEng degree. Those who choose a career path leading into management often have pursued a traditional MBA. Each of these options represents education in a traditional setting, usually elected early in one's career, culminating in a terminal degree. None of them acknowledges that the successful practicing professional engineer must learn for a lifetime.

In Figure 3 we indicate just some of the wide variety of knowledge and skills that are required by the practicing professional engineer. For the most part, this knowledge and these skills are acquired "on the job" through relevant experience in professional practice. There also is specific knowledge that is general in nature and can be acquired in a wide variety of educational formats such as short courses, self-paced courses, formal distance education courses and the like. Yet very little of this advanced professional education is obtained in a traditional academic setting since few practicing engineers are willing to put career and family on hold so they can participate in full-time study.

The National Collaborative Task Force has established a framework for advanced professional education that addresses the professional development needs of practicing engineers in industry or government service. The program has been developed around the knowledge and skills required at all stages of professional development from entry level through chief engineer level. It also acknowledges the way practicing professional engineers grow and learn.

Following Conrad's work,[8] the National Collaborative has identified several attributes of top-quality professional graduate programs:

- Core Fundamental Courses
  These bring to a new level the participants understanding of fundamental engineering subjects

- Core Technical Courses
  These strengthen the participant's grasp of specialized topics directly related to his or her industrial activity

- Total Immersion in the Program
  Because the participant is engaged in program activities that are directly relevant to and part of his or her work activities in industry, the program is not viewed as a "part-time" educational experience

- Individualization
  The program is tailored to meet the professional growth needs of the participant so the participant and the sponsoring industry derive the maximum educational benefit

- Substantive Thesis Project
  This project is directly related to the participant's work activities and is chosen to expand his or her professional capabilities

- Faculty Involvement in the Program
  The core faculty and adjunct faculty associated with the program assist the student to craft his or her program of study and actively guide the his or her project work

- Faculty Engagement in Professional Practice
  Faculty have extensive professional experience at the highest levels of technology leadership

These attributes have been incorporated in a program of advanced professional education for practicing professional engineers. The program is designed to provide the knowledge and skills required as the engineer grows from entry level to the highest level of engineering leadership for innovative technology development.

Recognizing that the program must be tailored uniquely either for an individual engineer or a small group of engineers at a specific company, the National Collaborative Task Force previously put forth a general framework for the Master of Engineering, the Doctor of Engineering, and Engineering Fellow degree.[11] These are presented here as Appendix C.

4.1 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 should have a minimum of six months and preferably two years experience in the practice of engineering. It is expected that the participant will develop a thorough understanding of his or her company's core technologies. As appropriate, the participant will acquire additional general engineering knowledge necessary for the success of a relevant technology development / technology improvement project. 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.

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.

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.

5. Conclusions

The National Collaborative Task Force has identified the activities primarily associated with the practice of engineering in industry and government service. The way that practicing engineers grow professionally has been studied and the knowledge, skills, and responsibilities associated with nine stages of professional maturation, autonomy, and responsibility in engineering practice have been identified. Using this knowledge as a basis, the Task Force has established a program of advanced engineering education for practicing professional engineers that is designed to foster engineering leadership at all levels of engineering practice. The engineer leaders program enables the practicing engineer to grow professionally from entry level (the Master of engineering degree) through mid-career (the Doctor of Engineering degree) to senior career (the Engineering Fellow degree).

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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 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

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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

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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

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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

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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

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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

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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

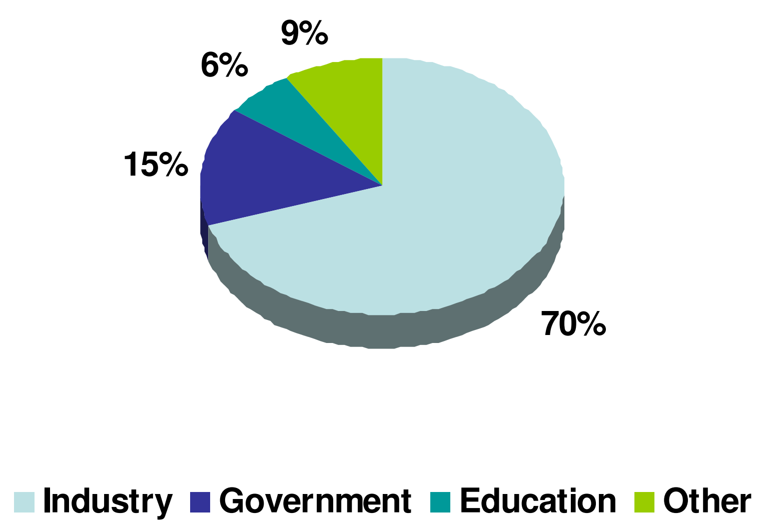
  a) Residency Component
  Full-time employment in engineering practice in industry/government service

  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.

(A) Employment



(B) Function

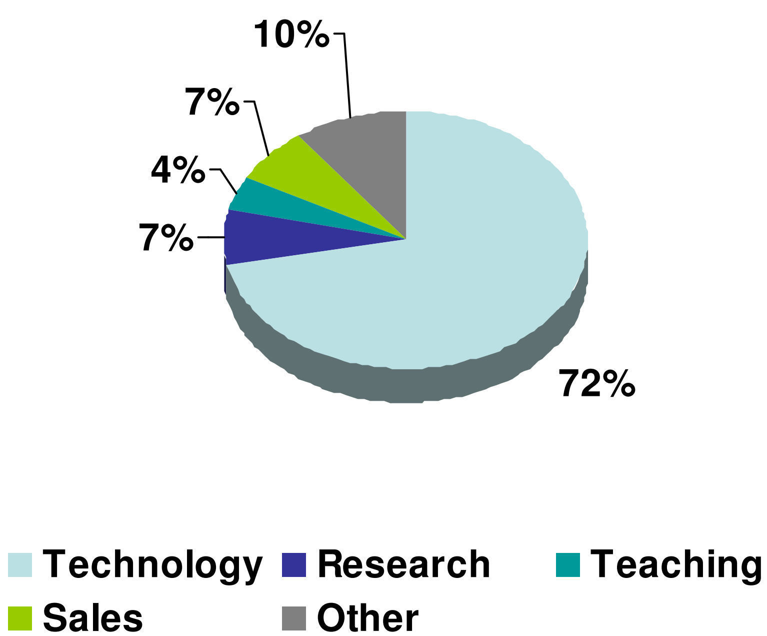


Figure 1: Activity Profiles of the Professional Engineer in Practice

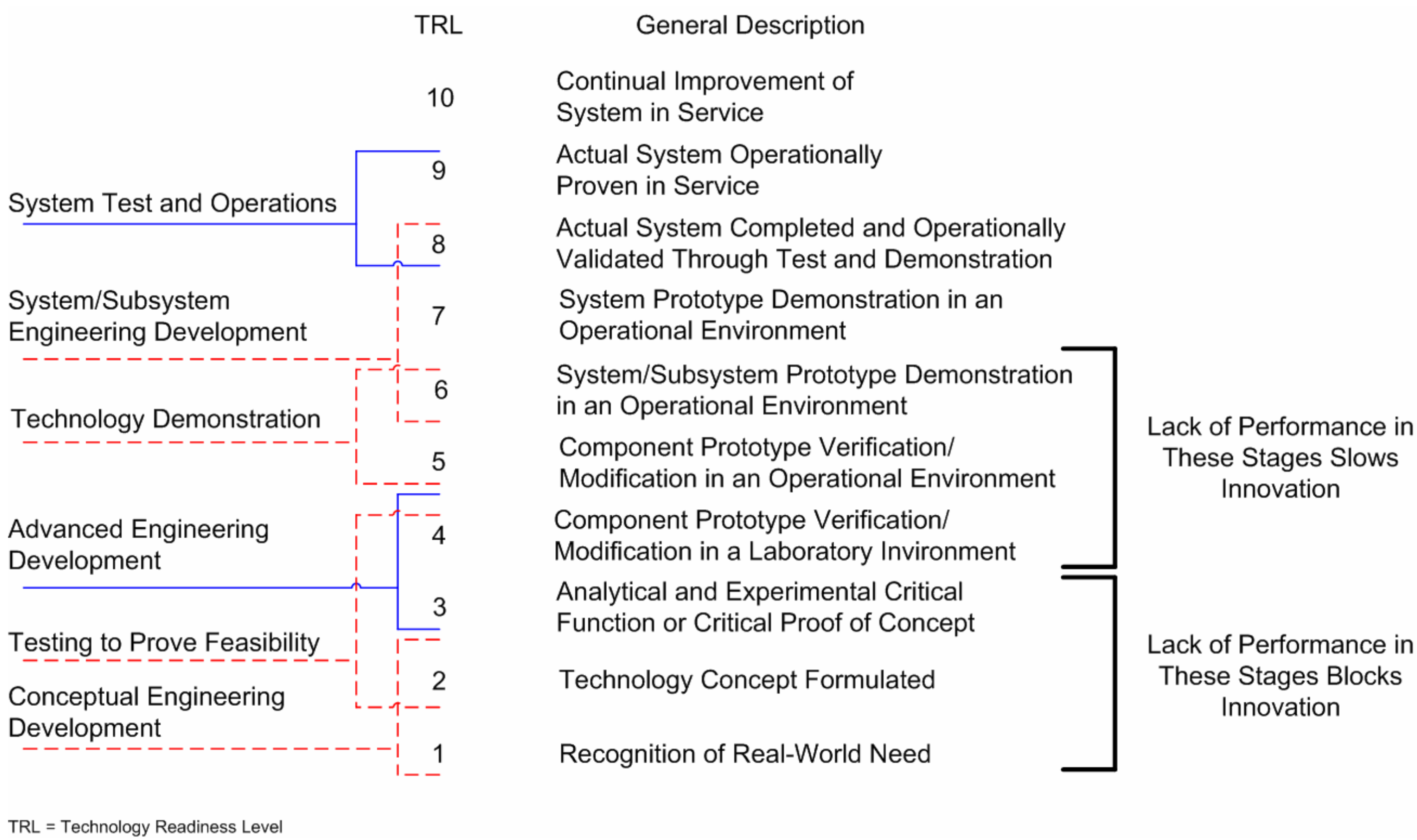


Figure 2: Technology Readiness Levels in the Practice of Engineering for Technology Innovation

Figure 3: **Lifelong Learning and Growth in Engineering for Technology Innovation**