AC 2007-1869: AN INDUSTRIAL ENGINEERING BODY OF KNOWLEDGE?

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An Industrial Engineering Body of Knowledge?

Abstract

Civil engineers have a defined Body of Knowledge. Mechanical engineering currently has a Body of Knowledge task force focused on the future of mechanical engineering education. Can we agree on an industrial engineering Body of Knowledge, or at least agree on outcomes that distinguish industrial engineering (IE) from other engineering disciplines? The ABET program criteria for industrial engineering state only that

> "The program must demonstrate that graduates have the ability to design, develop, implement, and improve integrated systems that include people, materials, information, equipment, and energy. The program must include in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices."

Other than the requirement for systems integration involving people, material, information, equipment, and energy, nothing distinguishes the IE program criteria from the general criteria specified for all engineers.

This paper reports the results of a study of the program educational objectives, outcomes, and curricula used by IE (or similarly named) programs in their ABET continuous improvement plan. The objective of the study was to identify outcomes common to industrial engineering programs that distinguish industrial engineering from other engineering disciplines.

Introduction

Some engineering disciplines have a defined Body of Knowledge (BOK). The Civil Engineering Body of Knowledge for the 21st Century[1], perhaps the most noted BOK, adds four outcomes to the eleven outcomes (Criterion 3 - a through k)[2] currently required for engineering accreditation by the Accreditation Board for Engineering and Technology. Table 1 lists those additional outcomes, which are viewed as "broadening and deepening"[1] current ABET outcomes.

Table 1. New Civil Engineering BOK Outcomes

Outcome	Statement: The 21st century civil engineer must demonstrate[1]:
Criterion 3, a-k (1 – 11)	. . .
12.	An ability to apply knowledge in a specialized area related to civil engineering.
13.	An understanding of the elements of project management, construction, and asset management.
14.	An understanding of business and public policy and administration fundamentals.
15.	An understanding of the role of the leader and leadership principles and attitudes.

The topics in Outcomes 13 through 15 in Table 1 are discussed extensively as requirements engineers of the future in *Educating the Engineer of 2020*[2]. The Body of Knowledge Committee of the American Society of Civil Engineers viewed these outcomes as “raising the bar” and encouraged “societies representing other engineering disciplines to also consider the necessity for and ramifications of ‘raising the bar’ in the long-term interest of maintaining public safety, health and welfare.”[1]

Given the historical role of industrial engineering in engineering economy and the claim that industrial engineering is the engineering discipline that is best suited for upper management, the civil engineering BOK outcomes 13 through 15 could naturally be expected of industrial engineering students. However, there has not yet been a unified call for change in the industrial engineering academic community.

The American Society of Mechanical Engineers (ASME) also has a Body of Knowledge Task Force, which has published “A Vision of the Future of Mechanical Engineering Education.”[3] This task force is considering how topics such as neural engineering and nanotechnology should influence requirements for basic science and mathematics. In addition, the ASME Engineering and Technology Enterprises organization has embarked upon strategies to improve “knowledge and community.”[5] This organization sees its activities as leading to new bodies of knowledge that solidify ASME’s importance to mechanical engineers. At the same time, new bodies of knowledge provide ASME with new income sources associated with codification and management of the bodies of knowledge.

An example of the ASME strategy can be found in ASME’s partnership with ASCE, AIChE, and AIME to establish Engineering Management Certification International (EMCI) to provide standards and certification for the engineering management. The Engineering Management Ceritification Body of Knowledge (EMC-BOK™)[6] specifies eight general domains, 49 knowledge areas, and 170 sub-knowledge areas. Table 2 provides some selected examples of knowledge that might be taken from a typical industrial engineering curriculum. According to Chor Weng Tan, the recently retired managing director for education at ASME, the “engineering management certification program, with its requirement for continuous professional development for recertification combined with an engineer’s academic and practical knowledge, might be the best option toward becoming a good engineering manager for the new age.”[7]

Table 2. Selected Examples from EMC-BOK™

Domain	Knowledge Area
Market research, technology updates, and environmental scanning	Business research & forecasting tools, risk analysis, trend analysis
Planning and adjusting business strategies	System design and life cycle engineering, financial risk management strategies & models
Developing products, services, and processes	Manufacturability, product/process creation (product or service specifications)
Engineering operations and change	Resource planning, project management techniques, scheduling, TQM, operations systems analysis
Financial resources and procurement	Engineering economic analysis techniques, inventory control procedures & supply chain management

The American Society for Engineering Management has worked to define its own Body of Knowledge and has taken steps to establish certification requirements for MS programs in engineering management.[8]

In other engineering disciplines, the Institute of Electrical and Electronic Engineers (IEEE) Computer Society and the Association for Computing Machinery ACM has worked on a Software Engineering Body of Knowledge (SWEBOK)[9]. Table 3 provides selected examples from the Software Engineering BOK that are related to a typical industrial engineering curriculum.

Table 3. Selected Examples from the Software Engineering BOK.

Knowledge Area	Topics
Software design	Design quality and metrics
Software engineering management	Management process, measurement
Software engineering process	Life cycle models, benchmarking, process evaluation,
Software evolution and maintenance	Maintenance process, measurements
Software quality analysis	Standards, process plans, measurement

As a final example of efforts to define a body of knowledge, the IEEE Computer Society and ACM Joint Task Force on Computing Curriculum – Computer Engineering (CCCE) have defined the computer engineering body of knowledge[10].

Industrial Engineering Body of Knowledge

Can industrial engineers agree on a Body of Knowledge or at least on outcomes that distinguish industrial engineering (IE) from other engineering disciplines? The ABET program criteria[2] for industrial engineering state only that

> "The program must demonstrate that graduates have the ability to design, develop, implement, and improve integrated systems that include people, materials, information, equipment, and energy. The program must include in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices."

Other than the requirement for systems integration involving people, material, information, equipment, and energy, nothing distinguishes the IE program criteria from the general criteria specified for all engineers. One might reasonably ask: *Can the program criteria for industrial engineering assist in defining the IE discipline without loss of flexibility to academic programs?*

This paper reports the results of a study of the program educational objectives, outcomes, and curricula used by IE (or similarly named) programs in their ABET continuous improvement plan. The objective of the study was to identify outcomes common to industrial engineering programs that distinguish industrial engineering from other engineering disciplines.

Industrial Engineering Outcomes Study. The IE outcomes study originally stemmed from ABET EC 2000 assessment efforts at [redacted] in an attempt to address the question: *How does our undergraduate program compare to other IE programs in terms of curriculum, outcomes, objectives, and resources?*

The approach focused on building a database to include curriculum requirements of topics, and credit hours, as well as program educational objectives and outcomes. The analysis attempted to address the following questions:

1. How are the ABET general engineering program outcomes interpreted and achieved in accredited industrial engineering programs?
2. Are there knowledge, skills, and tools that all BSIE graduates are expected to possess, regardless of the size and focus of the programs from which they graduate?
3. How do these outcomes distinguish industrial engineering from other engineering disciplines?

A database was developed to catalog the objectives, outcomes, and curricula of most of the approximately 100 ABET-accredited industrial engineering bachelor's programs. Data were collected over a one-year period. A transition was observed as *program objectives* and *program outcomes* were defined more fully in the ABET criteria. Outcomes were classified based on their relationship (or uniqueness) to those listed in ABET Criterion 3 a through k. An outcome was categorized as

- Identical to one of the a-k outcomes,
- A combination of two or more of the a-k outcomes,
- An extension of one of the a-k outcomes,
- An interpretation of one of the a-k outcomes, or
- An addition to the a-k outcomes.

The analysis included a comparison of curricula with objectives, outcomes, and program name; identification of common and unique outcomes; and a summary of program educational objectives used by accredited programs.

Using the information from the accredited programs, the goal was to identify common expectations across BSIE curriculagrams. Curriculum results were not very different from those reported by Fraser[11], but additional details for specific industrial engineering courses are provided in Table 4. The summary includes the percentage of IE programs requiring the course, the average semester credit hours if the course is required, and average credit hours for the topic over all programs. Work methods courses were difficult to categorize so several similar topics are shown.

ABET Program Outcomes for Industrial Engineering. Table 5 provides typical outcomes used by industrial engineering programs in interpreting or extending outcomes a through k. Many of the interpretations involve integrated systems, as specified in the existing program criteria. Table 6 shows examples of outcomes that are in addition to those required in Criterion 3 a-k.

Table 4. IE Curriculum Summary

Industrial Engineering Courses	Percent Schools Requiring Course	Average Credit Hours If Required	Average Credit Hours, All Schools
Computer/Automated Manufacturing	47%	3.81	1.79
Design of Experiments	65%	2.96	1.93
Engineering Design Process	23%	3.90	0.91
Engineering Economics	96%	3.22	3.09
Ergonomics	67%	3.46	2.33
Ethics	24%	2.47	0.61
Facilities including Material Handling	74%	3.20	2.38
General Manufacturing	21%	3.35	0.72
Information Systems	39%	3.39	1.31
Required Outside Internship	9%	1.52	0.14
Introduction to Industrial Engineering	56%	2.32	1.30
ISE Elective	84%	8.34	6.98
Leadership	18%	2.44	0.45
Manufacturing Process ie casting, forming	71%	3.32	2.37
Material Handling	8%	3.13	0.26
Operations Research	98%	5.36	5.25
Production Control	89%	3.47	3.08
Project Management	44%	3.28	1.44
Quality Control	82%	3.15	2.57
Safety	14%	3.00	0.43
Seminars	31%	1.18	0.36
Senior Design	95%	4.06	3.85
Simulation	91%	3.33	3.02
Statistics	95%	4.00	3.80
Systems	40%	3.45	1.37
WorkDesign	8%	2.88	0.23
Ergo/Work Design/Methods/Measurement	22%	3.12	0.70
Work Methods/Measurement/Design	38%	3.14	1.19
WorkMethods/Measurement	13%	3.15	0.42

Table 5. ABET Criterion 3 Outcomes Applied to Industrial Engineering

	Outcome	IE Interpretations and Extensions
a.	An ability to apply knowledge of math, science, and engineering	1. An ability to apply math, science, and engineering to IE-type problems (related to systems that produce products and services) 2. An ability to apply knowledge of mathematics, probability, and statistics, as well as physical, social, and computer sciences to IE and business problems 3. An ability to apply knowledge of mathematics, science, and engineering to process-related problems associated with production planning, inventory, scheduling, logistics, and quality in manufacturing, distribution, and service organizations
b.	An ability to design and conduct experiments, as well as to analyze and interpret data	1. An ability to apply knowledge in probability and statistics to design and conduct statistically valid experiments involving risk and uncertainty, to measure process performance characteristics, and to determine causal relationships in processes 2. An ability to design and conduct experiments, as well as to model, analyze, and interpret data
c.	An ability to design a system component, or process to meet the desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	1. An ability to model processes and complex systems 2. An ability to design an integrated system that includes people, materials, information, equipment, and energy 3. An ability to design a system component, or process to meet the desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, including an ability to identify important design criteria, identify important design constraints, develop engineering design specifications, select and apply appropriate techniques, skills, and tools, assess efficiency and effectiveness, assess with respect to economic and quality considerations.

Table 5. ABET Criterion 3 Outcomes Applied to Industrial Engineering (continued)

d.	An ability to function on multidisciplinary teams	1. An ability to provide leadership within a team 2. An ability to manage a team project with respect to time and budget constraints
e.	An ability to identify, formulate, and solve engineering problems	1. An ability to identify, formulate, and solve engineering problems related to integrated systems that include people, material, information, equipment, and energy 2. An ability to recognize, model, and develop integrated solutions to large-scale, socio-technical problems.
f.	An understanding of profession and ethical responsibility	1. An understanding of the NSPE Code of Ethics and an appreciation of social and legal concerns 2. A knowledge of the code of ethics endorsed by IIE 3. An understanding of the importance of professional registration (the knowledge to become a PE)
g.	An ability to communicate effectively	1. An ability to communicate in ways appropriate to a particular audience 2. An ability to sell solutions 3. An ability to communicate effectively within and between teams 4. An ability to communicate in written, oral, and graphical forms
h.	The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	1. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal contest 2. The broad education necessary to understand the impact of engineering solutions in a business context, both locally and globally
i.	A recognition of the need for, and an ability to engage in lifelong learning	1. An understanding of the live nature of engineering and the need for and resources available for life-long learning 2. An understanding of the need for further education and self-improvement 3. A recognition of the importance of professional development through involvement and leadership in technical societies such as IIE

Table 5. ABET Criterion 3 Outcomes Applied to Industrial Engineering (continued)

j.	A knowledge of contemporary issues	1. A knowledge of contemporary issues that affect workplace efficiency and effectiveness 2. A knowledge of contemporary issues including global communication 3. A knowledge of contemporary issues related to the socio-economic, political, and environmental implications
k.	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	1. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice including economic analysis, information systems design, project management, ergonomic analysis, computer technologies, data collection tools and techniques, math modeling, simulation modeling, . . . 2. An ability to use tools to integrate information, people, and facilities for the purpose of predicting productivity, quality, safety, and associated costs

Table 6. Additional Industrial Engineering Outcomes

l.	An ability to understand the human components of a system and incorporate human capabilities in the design of safe system environments and jobs
m.	An ability to improve processes (an ability to apply continuous improvement)
n.	An ability to integrate the engineering and business processes of an organization
o.	An ability to manage integrated systems of people, technologies, material, information, and equipment
p.	An ability to perform feasibility studies and financial analysis of projects
q.	A working knowledge of manufacturing process and systems
r.	A knowledge of simulating and predicting the system’s behavior under specified conditions
s.	An ability to lead quality and productivity improvement projects

Industrial Engineering BOK Implications. Based on the curriculum, objective, and outcome analysis, the most common topics required or cited for industrial engineering programs include the following:

- Probability and statistics
- Economic analysis
- Operations research and simulation
- Quality methods
- Project management
- Ergonomics and work measurement / work design

Although not every program requires all six topics, it does not seem too onerous or inflexible to expect IE programs to require at least four of the six topics.

In addition the performance metrics of productivity, quality, and cost have long been associated with industrial engineering. Again, it does not seem burdensome to expect that any IE student would have a basic understanding of productivity, quality, and cost.

These two examples of topics and metrics could help to specify an IE Body of Knowledge. Missing is any consideration of new topics on the horizon and their effect on industrial engineering.

Similar to more explicit program criteria, an industrial engineering BOK would provide better clarity for programs in trying to meet accreditation requirements, as well as for program evaluators in assessing the programs. With a BOK and more explicit criteria, the public would also have a clearer understanding of industrial engineering.

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