An Approach to Determine the Industrial Engineering Body of Knowledge through Concept Mapping

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Abstract – Industrial engineering, both as a discipline and as a profession, is at a pivotal point in its evolution. The academic discipline is almost one hundred years old, with the first department established in 1908 at the Pennsylvania State University (Pennsylvania State University, 2007). Academic departments of industrial engineering are disappearing or being merged with other engineering departments or, in some cases, business departments. Although industrial engineering plays a critical role in the analysis, design, development, implementation, and improvement of most systems which have a human component, the concepts, principles, and methods of industrial engineering are still neither well defined nor uniformly agreed upon. Even the name is controversial, and, perhaps, misleading. Originally, it was reflective of the primary area of application – manufacturing industries; but today, practitioners are found in service organizations as well. The lack of consensus regarding industrial engineering practice and the requisite competencies creates confusion and has serious consequences for the evaluation, acquisition, and application of industrial engineering knowledge. This paper presents an application of concept mapping to identify and organize a body of knowledge for industrial engineering. This approach provides a systematic method to describe the industrial engineering discipline. Having a body of knowledge can assist organizations define and improve the industrial engineering competencies of their workforces; and it can help educational institutions define industrial engineering curricula. The latter is the primary objective of this study

Keywords: Industrial Engineering, Curriculum, Concept Mapping, Body of Knowledge.

INTRODUCTION

The industrial engineering (IE) criteria as stated by the Accreditation Board for Engineering and Technology (ABET) does not have a criteria that distinguishes its curriculum from other engineering disciplines beyond the requirements for systems integration. Specifically, that criterion is as follows:

> "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

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include in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices." (Engineering Accreditation Commission)

The above definition is based on the premise that IE is a discipline, which implies that certain specific characteristics should be evident. The characteristics as defined by Liles et al are the following: *(1) a focus of study, (2) a world view or paradigm, (3) a set of reference disciplines used to establish the discipline, (4) principles and practices associated with the discipline, (5) an active research or theory development agenda,* and *(6) the deployment of education and promotion of professionalism* [Liles et al., 1].

The essential emphasis of IE is on systems integration and incorporates supporting sub disciplines relative to the various systems components named in the definition (e.g., ergonomics, plant layout, planning and scheduling). As an engineering discipline, IE builds upon the fundamentals of science, mathematics, and humanities. It involves systematic approaches to problem solving and supports an active research agenda which includes: analysis and design of systems, process improvement, and management of system resources. Practitioners, educators, and students look to the principal professional society, the Institute of Industrial Engineering (IIE), for the control of standards, dissemination of information, and general oversight responsibilities. Through membership in IIE practitioners and academicians have a forum for sharing new ideas and anecdotal experiences related to practice. IIE provides an identity for the discipline. Through its research conference academicians have the ability to showcase research and identify opportunities for collaboration through a network of scholars with similar interests. Thus, IE seems to possess all of the necessary characteristics of a discipline. The next question is whether IE has transformed itself into a profession. The answer offered is "YES". The basis for this response follows.

First, IE is an engineering discipline; and, as a subset of engineering, which is accepted as a profession, which IE is also. Many agree with this logic, while others do not [2]. Engineering, in general, is defined by ABET as "the profession in which a knowledge of the mathematical or physical sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. In a stricter sense, however, a profession is characterized by special qualifying characteristics. According to Webster's Unabridged Dictionary, as quoted by Kemper [Kemper, 3], a profession requires specialized knowledge and often requires considerable preparation in skills, methods, and principles. Thus, associated with a profession is a specialized body of knowledge, and preparation for it includes training in applying that knowledge.

Review of requirements for a profession as defined by others, such as the American Bar Association (1995), the American Board of Internal Medicine (1994), and the American Medical Association (2007) reveals some common criteria as basic elements for "what it means to be a professional" [4,5,6]. A professional is a person who:

1. has mastery of a complex body of knowledge and skills used in the service of others ;
2. demonstrates accountability to the public at-large and profession in common, and satisfies performance measures established by the;
3. is governed by a code of ethics;
4. expresses and demonstrates commitment to competence, integrity, and morality, exhibits altruism, and promotes the public good within their domain.
5. demonstrates autonomy in practice and judgment, and accepts the responsibility associated with the privilege of self regulation; and
6. exhibits a professional spirit which results from associating together people that adhere to a common ideal which puts service above gain, excellence above quantity, self-expression above pecuniary motives and loyalty above individual advantage.

So, what does it mean to be an "industrial engineering professional"? This question is answered relative to the above six criteria. An industrial engineering professional receives a formal education, generally accredited by ABET; often taking the Fundamentals of Engineering (FE) examination before graduation. After working and obtaining experience, the professional may take the Professional Engineer (PE) exam. If it is passed, the practicing IE will become a licensed, professional engineer. As a PE, the Engineering Code of Ethics binds the licensed, professional IE. Many IE's are members of the professional society, Institute of Industrial Engineers (IIE) or those of sub disciplines.

Therefore industrial engineering, as a discipline and as a profession, qualifies for a succinct and independent body of knowledge (BOK). The definition cited previously, and generally accepted, for the discipline of IE implies that the

IE BOK should provide content sufficient to develop those intellectual skills necessary to integrate the components and activities associated with complex and unstructured systems.

The goal of this paper is to propose a systematic approach to developing an industrial engineering BOK that incorporates core and supporting concepts and links these concepts into an integrated understanding of the discipline.

METHODOLOGY

The ABET program criteria provides a starting point for addressing the knowledge and skills needed by practicing industrial engineers. According to the Institute of Industrial Engineering, the focus of study for industrial engineering is "how to design, develop, implement, and improve integrated systems that include people, materials, information, equipment, and energy." These system-related criteria, with the addition of analysis, reflect generally accepted approaches to problem solving. To begin, we develop a working definition for each of these activities.

Analysis involves obtaining a clear definition of the problem, the collection of data about it, and application of tools to determine the causes. **Design** involves testing to determine the ideal solution from among alternatives. **Development** requires the acquisition and structuring of resources to create that desired solution. **Implementation** puts the developed solution into practice with strategies for its use; and **Improvement** ensures that the implemented solution continues to address the initial problem and respond to new opportunities.

In order to get an in-depth understanding of these activities, concepts maps are applied. This map is a graphical method for presenting thoughts, theories, and or concepts [Besterfield Sacre et. al., 7] it is an effective tool for developing the body of knowledge for IE. Joseph Novak developed the concept map as a tool for representing knowledge [Novak & Gowin, 8]. The concept map constitutes a technique for the visualization of a knowledge structure. A concept map is comprised of nodes, representing concepts, and links representing the relationships between concepts. Concept maps have been used for a variety of educational purposes [Jonassen, 9] [Novak, 10]. Primarily, however, they have been used for assessment of students or of programs. Thus, usage as a design tool is a novel usage of concept maps in education. This design effort includes three components: *analysis* of the problem; the creation of a solution; and *testing*, to ensure that the design solution has solved the problem. An example of a concept map used to describe engineering, in general, is shown in Figure 1 [Turns et al., 11]. Note that “Design” is in the center, and thus, fundamental to engineering.

Figure 1, an example concept map shows 18 important concepts in engineering and some relationships among these concepts. The nodes of the map contain the concepts, the links between the nodes capture the relationships among concepts, and the labeling of the links provides information about the nature of the relationships. These maps are based on associative networks of knowledge [Collins, et al, 12]. The central premise is that knowledge is stored in a network format where concepts are connected to each other.

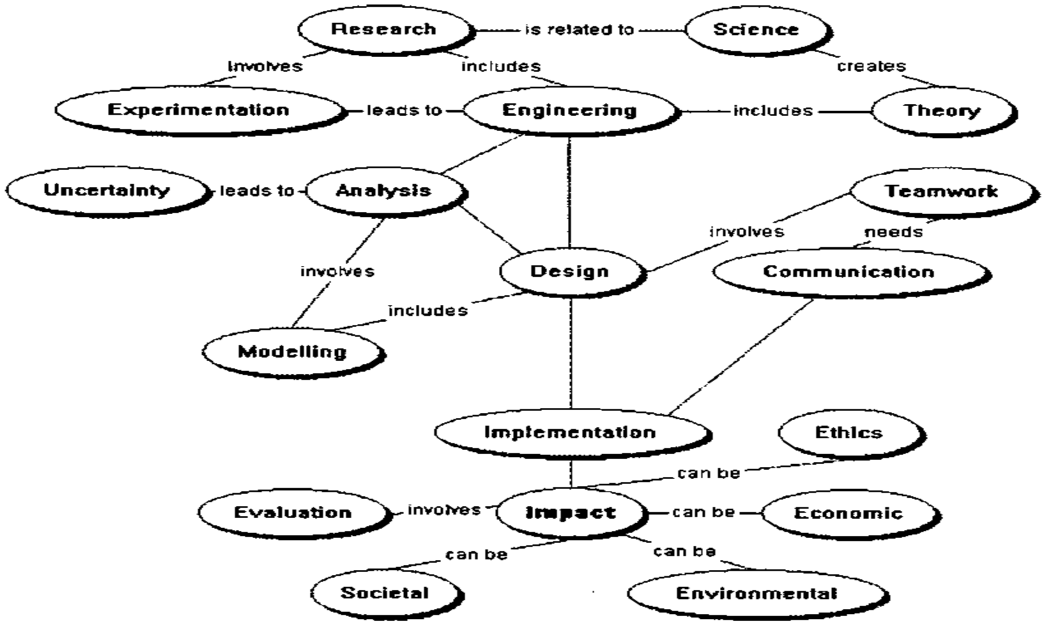

Figure1: Engineering Concept Map

(Source: *Concept Maps for Engineering Education: A Cognitively Motivated Tool Supporting Varied Assessment Functions* by Jennifer Turns, Cynthia J. Atman*, Member, IEEE*, and Robin Adams. IEEE Transactions on Education, Vol. 43, NO. 2, May 2000.)

Steps used to construct the concept map involve [Leung, 13]:

1. Focus on a theme and then identify related key words or phrases as labels.
2. Rank the labels from the most abstract and inclusive to the most concrete and specific
3. Cluster labels that function at similar levels of abstraction and those that interrelate closely
4. Arrange labels into a diagrammatic representation
5. Add attributes to each label if/as appropriate
6. Connect the labels with linking lines and name each link-line with a relationship description.

There are various software packages available to assist in developing of the maps. Any program that can draw shapes and arrows can be used to draw a concept map. The graphics program, Microsoft Visio, was used to create this initial IE concept map. This choice was made because of familiarity. Also, there are graphic programs developed specifically to be used for developing concept maps. One in particular is Cmap. The CmapTools program allows users to construct, navigate, share and assess concept maps. It is free for both commercial and non-commercial users. (More information is available at cmap.ihmc.us).

The maps may have different structures, based on the nature of the relationships. The map in Figure 1 is a network structure, wherein the nodes may be reached from a variety of directions. If, however, the relationships are hierarchical, the structure will be tree-like. This means that there is one path to any one node, starting from a root node. Hybrid structures are also possible, wherein the nodes on different levels may develop relations with multiple nodes on the preceding level. For the Industrial Engineering concept map, starting with the systems activities, and ascending to the tools and techniques applied and then down to the knowledge and skills required, the resulting structure is a hybrid.

THE IE CONCEPT MAP

The IE Concept Map was developed according to the above steps. The approach was based on the ABET program criteria for industrial engineering. Specific input to the steps follows:

1. Select: Focus on a theme and then identify related key words or phrases as labels. Our theme is industrial engineering and the key phrases are the activities used in systems

2. Rank: Rank the labels from the most abstract and inclusive to the most concrete and specific. The labels were ordered as they are generally encountered in structured problem solving or systems development.

3. Cluster: Cluster labels that function at similar levels of abstraction and those that interrelate closely. Based on brainstorming results, the levels were determined as follows: Level 1 – Systems Activities involved in Industrial Engineering; Level 2 – Tools and Techniques used during each activity; and Level 3 – Knowledge and Skills required in order to apply the tools and techniques.

4. Arrange: Arrange labels into a diagrammatic representation. The structure selected was an initial hierarchy that became a network as the structure was further decomposed.

5. Attribute: Add attributes to each label if/as appropriate.

6. Link and describe relationship: Connect the labels with linking lines and name each link-line with a relationship description. The relationships are stated in Step #3.

Figure 2 represents the results of brainstorming among students and faculty to determine the tools and techniques applied in the systems activities. Several of these are used in multiple system processes. For example, Design of Experiments may be applied in both Analysis and Improvement; and teamwork is required across all activities. Thus, teamwork is viewed as an integrating tool. Table 1 provides a summary of the interactions between levels 1 and 2 of the map. The problem solving steps in Table 1 correspond to level 1 elements of the IE concept map in Figure 2: 1=Analysis, 2=Design, 3=Development, 4=Implement, and 5=Improvement.

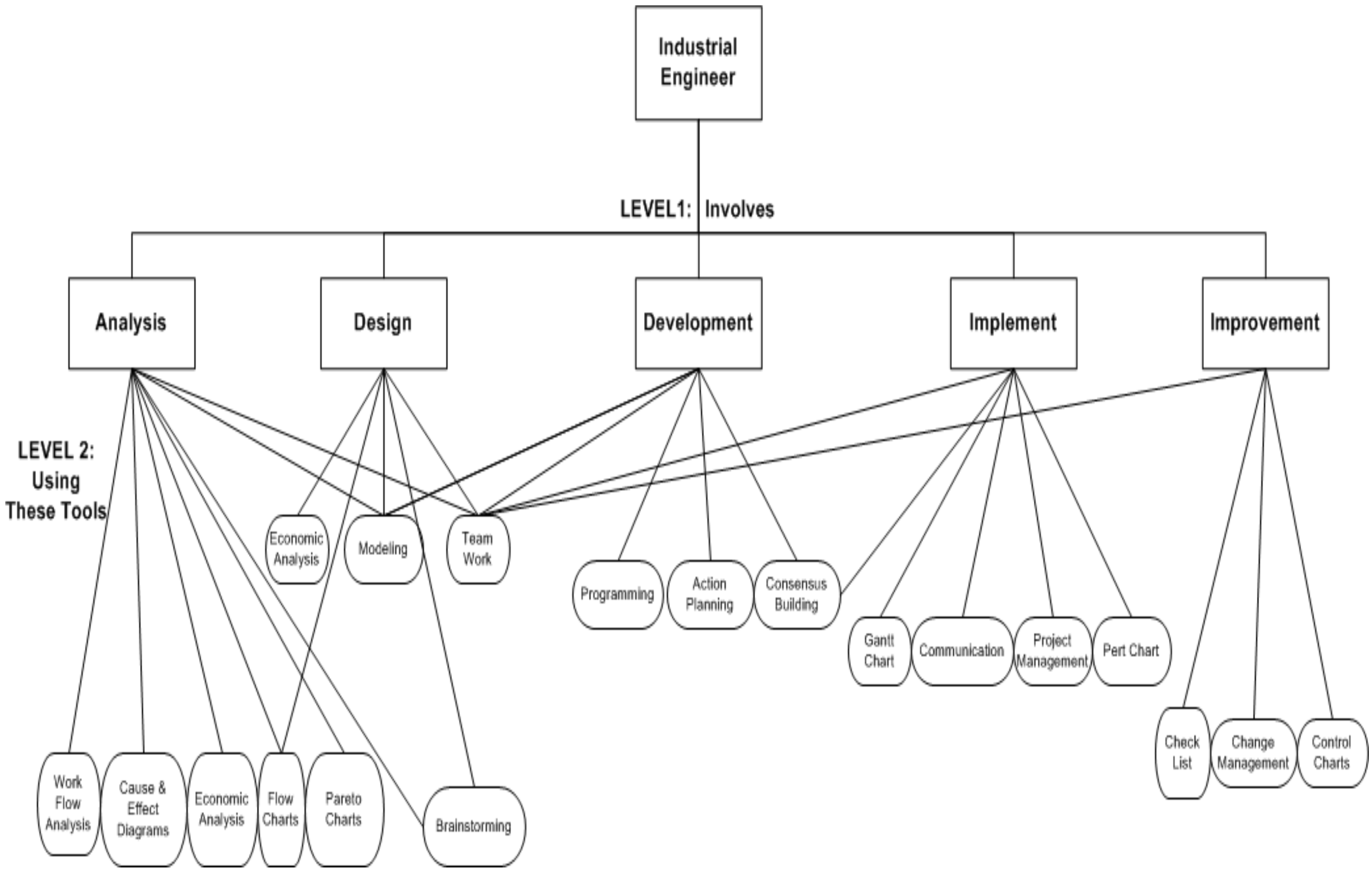

Figure 2: IE Concept Map

Tools & Techniques	Problem Solving Steps				
	1	2	3	4	5
Action Planning			X		
Brainstorming	X	X			
Cause & Effect Diagrams	X				
Check List					X
Consensus Building		X	X		
Control Charts	X				X
Economic Analysis		X			
Cost of Quality	X				X
Flow Charts	X	X			
Gantt Chart				X	
Pareto Charts	X				X
PERT Chart				X	
Work Flow Analysis	X				
Modeling	X	X	X		
Team Work	X	X	X	X	X
Programming			X		
Communication				X	
Project Management				X	
Change Management					X

Table 1: Levels 1 and 2 Interactions

The third level is the knowledge and skills required in order to apply the tools and techniques. This level is still being determined. Several iterations of discussions are required because this level will be used to create a curriculum map that incorporates the body of knowledge. The objective is to clearly identify topics needed to provide the skills and knowledge needed to apply the tools and techniques across the entire spectrum of activities to solve problems in systems of any area of application. The industrial engineer might know the details for specific application areas, but the IE will know how to manage the process and integrate the efforts into a comprehensive systematic approach.

Connection of the concept map and the curriculum map will enable the student to demonstrate comprehension, Level 2 of Bloom's Taxonomy [Bloom, 14]. The next step is for faculty to develop assignments so that students may demonstrate application (Bloom's Taxonomy, Level 3) of the concepts in new and diverse physical settings. This includes demonstrated connections across various settings and application areas; and, ultimately analysis, design, development, implementation and improvement of systems using an integrated systems approach.

Overarching all of the levels and tying components together among the levels are interlacing skills such as communications and interpersonal skills. Communications includes both written and oral applications of the concepts. Interpersonal skills are required for interactions among the people components of systems, between the IE and the people components, and throughout the managerial levels affecting the IE and the people components of the systems. The managerial skills are also critical in optimizing the utilization of other resources consumed by system processes.

FUTURE ENHANCEMENTS

The third level of the concept map presented has not been fully developed. The next step is to include input from academics outside of this department and practitioners to identify critical skills and knowledge. The department earlier surveyed its Board of Advisors for input and will also survey its alumni and industrial friends.

After completing this level of the map, the resulting structure will be presented to practitioners for validation. Additionally, assessment approaches will be mapped unto the structure. Some of these might include concept maps of the topics to demonstrate level of comprehension, peer evaluations, and case studies.

CONCLUSIONS

Renewing an entire four-year engineering curriculum is an ambitious undertaking and the project team has tried to match the scope of its efforts to the scope of the project. Only preliminary results from the project are available to date, but it is hoped that the steps that have been taken to date and the results that have been achieved will be helpful to others who might undertake future curriculum renewal projects.

Ultimately, a defined Body of Knowledge will provide Industrial Engineering students, faculty, and practitioners with a stronger connection between what IIE and ABET define as industrial engineering and what the practitioner does an industrial engineer. Perhaps, it will enable IE's to respond to "IE stands for Imaginary Engineer" with, "No, although we use our imaginations to solve problems on a system's scale, we are Integrating Engineers – without us, systems fall apart!"

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