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Possible Influences of the NSPE EBOK and the AAES/DOL Engineering Competency Model (ECM) on the CEBOK3

Dr. Stuart G. Walesh P.E., S. G. Walesh Consulting

Stuart G. Walesh, Ph.D., P.E., Dist.M.ASCE, and F.NSPE (stuwalesh@comcast.net, www.helpingyouengineeryourfuture.com) is an author; teacher; and an independent consultant providing leadership-management, engineering, and education-training services. Prior to beginning his consultancy, he worked in the public, private, and academic sectors serving as a project engineer and manager, department head, discipline manager, marketer, legal expert, professor, and engineering dean. Walesh's technical specialty is water resources engineering. His current principal research interest is using brain basics to help engineers, beginning as students, to work smarter, that is, be more effective-efficient and more creative-innovative.

He authored or co-authored six books and many engineering and education publications and presentations. His textbook Engineering Your Future: The Professional Practice of Engineering was published in 2012 and his textbook Introduction to Creativity and Innovation for Engineers was published by Pearson Education in 2016.

Walesh facilitated and/or made presentations at several hundred workshops, seminars, classes, webinars, and meetings throughout the U.S. and internationally. For the past 15 years he has been active in the effort to reform the education and early experience of engineers.

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Abstract

In 2013, the National Society of Professional Engineers (NSPE) completed development of the first-ever Engineering Body of Knowledge (EBOK). Then, in 2015, the U.S. Department of Labor (DOL) finished, with major inputs from members of the American Association of Engineering Societies (AAES), its first-ever Engineering Competency Model (ECM). The EBOK and the ECM appeared, respectively, five and seven years after the 2008 release of the current Civil Engineering Body of Knowledge – Second Edition (CEBOK2) and essentially just before starting the process that could lead to a CEBOK3.

This paper's purpose is to suggest that the EBOK and ECM warrant attention because their intents overlap with the CEBOK2's intent. Consistent with the paper's purpose, the intent and essentials of the EBOK and ECM are described.

More specifically, the EBOK is defined as the knowledge, skills, and attitudes (KSAs), collectively referred to as capabilities, required of an individual to enter practice as a professional engineer (licensed) in responsible charge of engineering activities that potentially impact public health, safety, and welfare. The overriding intent of the EBOK is to encourage ten identified engineering profession's members and stakeholders to use the EBOK to think about where they are and where they may want to go.

The ECM describes, using a tiered structure, engineering knowledge, skills, and abilities (not attitudes) collectively referred to as competencies. Unlike the EBOK, the ECM competencies are not connected to a particular milestone in an engineer's career and, even more specifically, are not linked to licensure. The ECM is designed to serve as a resource for practitioners and academics across all engineering disciplines.

The paper then suggests aspects of the EBOK and the ECM capabilities/competencies that are not explicit in the CEBOK2 outcomes and ought to be at least considered during the CEBOK2 update discussions. The seven relevant capabilities/competencies are: Client/Stakeholder Focus, Creative Thinking, Engineering Economics, Manufacturing and Construction, Operation and Maintenance, Quality Control - Quality Assurance, and Safety. The paper concludes by offering preliminary ideas on how those elements might be adapted to the next version of the CEBOK.

Keywords – Body of Knowledge, BOK, Civil Engineering Body of Knowledge, capabilities, CEBOK2, competencies, creative thinking, Department of Labor, Engineering Body of Knowledge, EBOK, Engineering Competency Model, ECM, KSAs, outcomes.

Introduction

The purpose of this paper is to suggest that the first-ever Engineering Body of Knowledge (EBOK) published by the National Society of Professional Engineers (NSPE) in 2013[1] and the first-ever Engineering Competency Model (ECM) completed in 2015[2] by the U.S. Department of Labor (DOL), with major inputs from members of the American Association of Engineering Societies (AAES), warrant attention by the American Society of Civil Engineers (ASCE) because their intents and contents overlap with the Society's CEBOK2[3].

This paper strives to achieve the stated purpose by:

- Explaining why the EBOK was developed and describing its features.
- Explaining why the ECM was developed and describing its features.
- Identifying capabilities/competencies in the EBOK and ECM that are not in the CEBOK2 and suggesting that they be considered for inclusion in a revised or new CEBOK.
- Offering ideas on how those capabilities/competencies might be adapted to the CEBOK.

On arriving at this point in the paper, the reader may notice, with some dismay, the large and diverse number of professional organizations and abbreviations. While they are necessary to provide adequate context, they will hopefully not detract from the paper's focus which is the elements or basic building blocks of the EBOK and the ECM. More specifically, the major thrust of the paper is to identify those elements that are not in the CEBOK2 for possible inclusion in the next form of the CEBOK.

Engineering Body of Knowledge

Why Develop the EBOK and Who Would Use It?

The National Society of Professional Engineers (NSPE) initiated the EBOK project for three reasons.[4] The first is to support the Society's vision, mission, and values. Second, to respond to the National Academy of Engineering's challenges in *The Engineer of 2020.* Third, build on discipline-specific BOK efforts such as those by ASCE in 2008, the American Academy of Environmental Engineers in 2009, the American Institute of Chemical Engineers in 2015[5], and others. (For others, see Appendix A in the paper "NSPE's Pan-Engineering BOK"[4].)

From the outset, the aspirational EBOK was envisioned as being useful, in many ways, to various members of the engineering profession and those with whom they interact. The EBOK would be the foundation on which professionals prepare for and build careers and from which they communicate about their profession to others. More specifically, as illustrated in Figure 1, various members of the engineering community and stakeholders in the engineering community can draw on and benefit from the EBOK.[4]

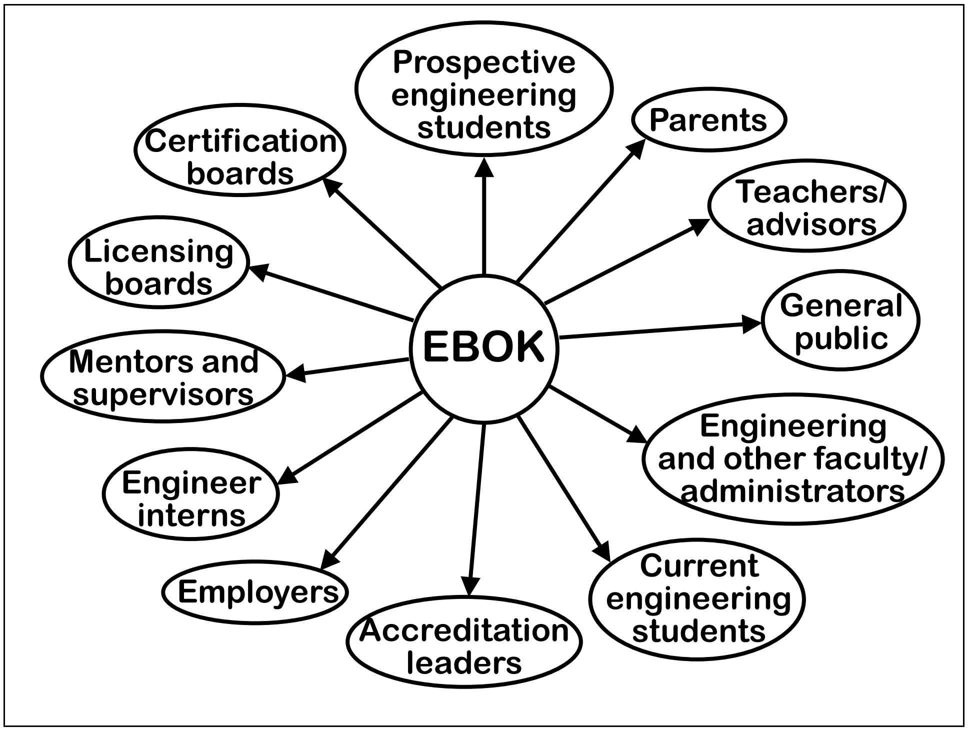

Figure 1. Members of and stakeholders in the engineering community can draw on and benefit from the EBOK.[4]

The EBOK Defined

"A profession's BOK is its common intellectual ground – it is shared by everyone in the profession regardless of employment or engineering discipline. The EBOK, as used in this paper, is defined as the depth and breadth of knowledge, skills and attitudes [KSAs] appropriate to enter practice as a professional engineer in responsible charge [licensure] of engineering activities that potentially impact public health, safety, and welfare. Within the BOK:

- Knowledge consists of comprehending theories, principles, and fundamentals
- Skills are the abilities to perform tasks and apply knowledge
- Attitudes are the ways in which one thinks and feels in response to a fact or situation

In broad terms, knowledge is what **one knows** in a fundamental sense, skill is what **one is able to do** with what one knows, and attitude is how **one responds** to a variety of situations."[4]

Capabilities and Abilities

EBOK KSAs are referred to as capabilities. Each capability is part of what an individual is expected to know and be able to do by the time of entry into professional practice in a responsible role.

Capabilities are usually acquired through a combination of engineering education and experience. NSPE does not attempt to indicate what aspects or parts of the capabilities are fulfilled through education and/or experience because these means may vary significantly across engineering disciplines and employment circumstances. In effect, the EBOK defines the "what," not the "how."

NSPE's capabilities in the EBOK are similar to the 24 outcomes used by ASCE in its BOK.[3] The word outcomes was originally considered by NSPE, but rejected because some contributors argued that it could be confused with the engineering program outcomes established by ABET.

A given capability typically consists of many diverse and specific abilities. The abilities are presented in the EBOK as examples; and are just that – examples, not all-inclusive lists. The specific abilities required in each engineering position and in each discipline will vary significantly.

The names of 30 capabilities comprising the EBOK are listed here and organized for clarity in three categories, namely, Basic or Foundational, Technical, and Professional Practice.[1]

Basic or Foundational Capabilities:
1. Mathematics
2. Natural Sciences
3. Humanities and Social Sciences

Technical Capabilities:
4. Manufacturing/Construction
5. Design
6. Engineering Economics
7. Engineering Science
8. Engineering Tools
9. Experiments
10. Problem Recognition and Solving
11. Quality Control and Quality Assurance
12. Risk, Reliability, and Uncertainty
13. Safety

14. Societal Impact
15. Systems Engineering
16. Operations and Maintenance
17. Sustainability and Environmental Impact
18. Technical Breadth
19. Technical Depth

Professional Practice Capabilities:

20. Business Aspects of Engineering
21. Communication
22. Ethical Responsibility
23. Global Knowledge and Awareness
24. Leadership
25. Legal Aspects of Engineering
26. Lifelong Learning
27. Professional Attitudes
28. Project Management
29. Public Policy and Engineering
30. Teamwork

To reiterate, the names are just that, they do not describe the capabilities. For descriptions of the 30 capabilities refer to Appendix D in the EBOK report.[1] The description of each capability includes examples of supporting abilities which are presented in the Bloom Taxonomy format. An example of a capability description (Capability 5: Design) is included as Appendix A of this paper to illustrate the format and content.

Engineering Competency Model

Why Develop the ECM and Who Would Use It?

The U. S. Department of Labor arranges for the preparation of competency models. Each is “a collection of multiple competencies that together define successful performance in a defined work setting. [Each] model provides a clear description of what a person needs to know and be able to do – the knowledge, skills, and abilities – to perform well in a specific job, occupation, or industry… Competency models articulate the business and industry requirements that are essential components for the development of curriculum, skill assessment instruments, and certifications.

Competency models also facilitate the development of career pathways and career lattices providing the framework for career advancement. Competency models are the foundation for important human resource functions such as: recruitment and hiring, training and development, and performance management. Competency models generally are developed as a platform for these other resources.” As of March 2016, competency models had been developed for 26 highly varied occupations or industries.[6] In the context of engineering, the U. S. Department of Labor competency model is likely to be used by the members of and stakeholders in the engineering community shown in Figure 1.

The ECM Described

"The Engineering Competency Model identifies the knowledge, skills, and abilities needed for workers to perform successfully in the field of engineering."[2] Note that the ECM uses "abilities" in contrast with the EBOK which uses "attitudes." While there is a distinct difference between abilities and attitudes, the difference is not significant for the purposes of this paper.

"Abilities" as well as "knowledge" and "skills," are not defined in the ECM. Instead, they are lumped together into "competency" which is defined as "a cluster of related knowledge, skills, and abilities that affects a major part of one's job (a role or responsibility), that correlates with performance on the job, that can be measured against well-accepted standards, and that can be improved through training, development, and experience."[2]

As shown in Figure 2, the ECM is constructed as a pyramid consisting of five tiers. "The arrangement of the tiers in this shape is not meant to be hierarchical, or to imply that competencies at the top are at a higher level of skill. Instead, the model's tapered shape represents increasing engineering specialization and specificity. Its tiers are further divided into blocks that represent competency areas (i.e., groups of knowledge, skills, and abilities), which are defined using critical work functions and technical content areas."[2]

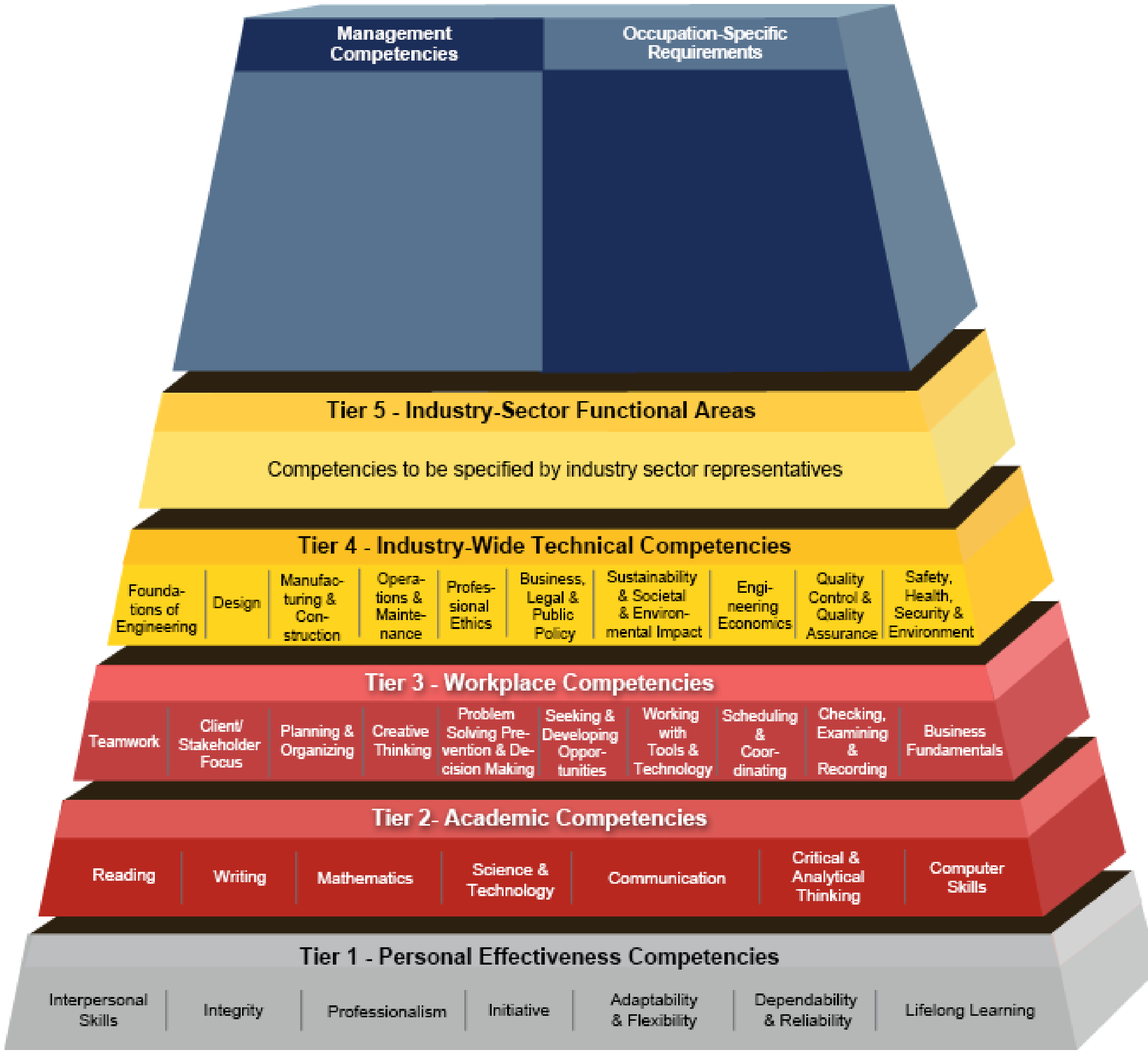

Figure 2. The ECM is constructed as a pyramid with higher tiers representing increased engineering specialization and specificity.[2]

Tiers 4 and 5 apply specifically to the engineering profession. Tier 4 “Industry-Wide Technical Competencies” are competencies applicable to essentially all engineering disciplines. Tier 5 “Industry-Sector Functional Areas,” which is vacant in Figure 2, is reserved for discipline-specific (e.g., civil engineering or some subset of that) competencies.[2]

Each of the 34 competencies -- building blocks -- used to construct the Figure 2 pyramid is described in the ECM report. For example the Tier 3 Creative Thinking block is explained as shown in Figure 3.

3.4 Creative Thinking: Generating innovative and creative solutions[2]

3.4.1 Employing unique analyses

- 3.4.1.1 Learn and use facilitation tools and methods that encourage creative and innovative thinking by individuals and groups.
- 3.4.1.2 Use original analyses and generate new, innovative ideas in complex areas.
- 3.4.1.3 Develop innovative methods of obtaining or using resources when insufficient resources are available.

3.4.2 Generating innovative solutions

- 3.4.2.1 Consider past successful approaches while also being open to fundamentally new ones.
- 3.4.2.2 Integrate seemingly unrelated information to develop creative processes or solutions.
- 3.4.2.3 Reframe problems in a different light to find fresh approaches.
- 3.4.2.4 Entertain wide-ranging possibilities and perspectives to develop new solutions.
- 3.4.2.5 Find new ways to add value to the efforts of a team and organization.

3.4.3 Seeing the big picture

- 3.4.3.1 Understand the pieces of a system as a whole and appreciate the consequences of actions on other parts of the system.
- 3.4.3.2 Monitor patterns and trends to see a bigger picture.
- 3.4.3.3 Modify or design systems to improve performance.
- *3.4.3.4* Demonstrate an ability to create a vision.

Figure 3. Explanation of Creative Thinking, a Tier 3 competency.[2]

As another example, consider Engineering Economics, a Tier 4 competency which is described in Figure 4.

4.8 Engineering Economics: Economics for application to engineering projects[2]

- 4.8.1 Prepare detailed cost estimates of capital and annual operating costs, maintenance and repair, and replacement costs for a project or component of a project, such as equipment, materials, assembly, inspection, modification, quality assurance, etc.
- 4.8.2 Calculate the return on investment, present worth and/or annual cost and benefit of a project having initial capital and annual operation, maintenance, repair, salvage value and replacement costs using appropriate interest, discount, and projected inflation rates.
- 4.8.3 Identify and quantify the economic risks associated with a project or product, including how warranty costs are considered for a product.

4.8.4	Compare design alternatives with varying cost profiles on a present worth or annual cost basis.
4.8.5	Interact with managers and other professionals in providing project economic information and opinions of project costs in financial analysis and financing process.
Knowledge Areas:	
4.8.6	Time value of money
4.8.7	Cost, including incremental, average, sunk and estimating
4.8.8	Economic analyses
4.8.9	Depreciation and taxes
4.8.10	Discounted cash flows (PW, EAC, FW, IRR, amortization)
4.8.11	Types and breakdown of costs (e.g., fixed, variable, direct and indirect labor)
4.8.12	Accounting (financial statements and overhead cost allocation)
4.8.13	Capital budgeting
4.8.14	Risk identification
4.8.15	Cost-benefit analysis
4.8.16	Profit and loss
4.8.17	Supply/demand
4.8.18	Net income statement, cash flow statement, balance sheet

Figure 4. Explanation of Engineering Economics, a Tier 4 competency.[2]

A Major Difference between the EBOK and the ECM

Recall that the definition of the EBOK includes "appropriate to enter practice as a professional engineer in responsible charge [licensure]." The EBOK is connected with a milestone, a specific point in an engineer's career, namely, licensure. Certainly most engineers would continue personal development after that milestone by using study and experience to broaden and deepen their KSAs.

In contrast, the ECM does not reference a career milestone. Instead, the ECM "is intended as a resource for further explorations of the competencies needed in this critical field. Users of the model are encouraged to add or subtract competencies as they see fit."[2]

While this major difference between the two models is important for understanding how they should be used, it does not detract from the purpose of this paper. Recall that the purpose is to identify those elements -- EBOK capabilities and ECM competencies -- that are not in the CEBOK2 for possible inclusion in the next form of the CEBOK.

EBOK and ECM Capabilities/Competencies Potentially Useful in the Next CEBOK

We turn now to viewing the EBOK and ECM as resources, as sources of capabilities and competencies that could be considered by those who will shortly examine the CEBOK2 for revision or for replacement as CEBOK3. A comparison of EBOK and ECM capabilities and competencies to CEBOK2 outcomes reveals elements of the former that are not in the latter. Those seven elements are shown in Table 1.

Table 1. Capabilities and competencies potentially useful in updating the CEBOK.

Significant Capability or Competency Not in CEBOK2 and Potentially Useful for a Revised or New CEBOK	In EBOK	In ECM
Client/Stakeholder Focus	--	X
Creative Thinking	--	X
Engineering Economics	X	X
Manufacturing and Construction	X	X
Operations and Maintenance	X	X
Quality Control and Quality Assurance	X	X
Safety[a]	X	X

a) The EBOK uses Safety and the ECM uses the broader Safety, Health, Security, and Environment.

For an example of a detailed analysis of whether or not a capability is included in the CEBOK, refer to the paper "Creativity and Innovation as a Part of the Civil Engineering BOK."[7] That analysis noted that "creativity or innovation appear in the rubric of only one outcome and in the discussions of only five outcomes." It concluded that "the report gives minimal attention to creativity/innovation. It does not present creativity/innovation as an essential element of the CEBOK." A similar, in-depth analysis could be done for the capabilities and competencies listed in Table 1.

The seven elements in Table 1 warrant consideration by ASCE as it examines the CEBOK2 for two reasons. First, the EBOK and ECM source reports post date by, respectively, five and seven years, the 2008 publication of the CEBOK2. Some aspects of the world of engineering education and practice change rapidly and, therefore, the two newer documents may reflect what are now viewed as more important emphases or topics than they were years ago.

Second, the EBOK and the ECM each are products of the integrated effort of many volunteer academics and practitioners representing a wide range of engineering disciplines. That kind of diverse participation enhances the credibility of the resulting products.

Preliminary Ideas on How the Seven Capabilities/Competencies Might be Reflected in the Next CEBOK

Consider two ways to explicitly include one or more of the seven elements in Table 1 in a third edition of the CEBOK or as an amendment to the second edition. The basic options for each are *adding an outcome*, while maybe deleting one or more, or *introducing a strong theme.*

Example of the New Outcome Option

Using Creative Thinking as an example of a new outcome, and drawing on an earlier similar example[7], the rubric form of the outcome could be as follows presented in the Bloom's Taxonomy format (as used in Appendix I of the CEBOK2 report[3]):

1. Knowledge -- Define creative thinking. (B)

2. Comprehension -- Describe how creative thinking differs from the traditional engineering problem-solving process. (B)

3. Application -- Use knowledge of creative thinking principles and methods to conceptualize potential solutions to a well-defined problem. (B)

4. Analysis – Analyze an actual problem using creative thinking principles and methods. (M/30)

5. Synthesis – Develop a creative thinking solution to an actual problem. (E)

6. Evaluation – Evaluate the creative thinking aspects of the solution to an actual problem.

Example of a Theme

The next version of the CEBOK could include many meaningful uses of "creative thinking," "creativity," and “create.”[7] Such words could appear in a rubric (as “create” does now in Outcome 15 of the CEBOK2) where they would have the most influence and the intent would be to encourage more creative thinking in defining issues, problems, and opportunities and in resolving them.

Consider, for example, Outcome 9, Design in CEBOK2. Level 5, Synthesis, reads "***Design*** a system or process to meet desired needs within such realistic constraints as economic, environmental, social, political, ethical, health and safety, constructability, and sustainability.” Creative thinking could be encouraged by adding this text “…and for some ***apply*** creative thinking principles and tools.”[7]

Outcome 9 for Level 6, the E level, is "***Evaluate*** the design of a complex system, component, or process and ***assess*** compliance with customary standards of practice, user's and project's needs, and relevant constraints." It could be expanded with this creative thinking statement: "…and for some, ***assess*** the extent to which creative thinking principles and methods were used."[7]

Outcome 10, Sustainability, at Level 3, the B level, states "***Apply*** the principles of sustainability to the design of traditional and emergent systems." It might be expanded with: "…and for the emergent ones ***illustrate*** how creative thinking principles and methods were used."[7]

Comparison of the New Outcome and Creativity/Innovation Theme Ideas

The *new outcome approach* would initially receive more attention because it is a new outcome. Some of that attention would be positive given the apparent interest of some faculty to take a more systematic approach to creativity in CE programs. In contrast, a new outcome would elicit some negative reactions partly because of the tendency of some faculty to connect outcomes with courses.

While creative thinking can be viewed as a knowledge-skill-attitude set, like most outcomes, it can also be seen as a way of thinking and, therefore, applicable across all or most outcomes. Therefore, a new outcome could serve two functions.

The *theme approach,* while it might not attract as much initial attention as the new outcome option, may enjoy more sustained attention because references to various aspects of creative thinking would appear in many outcomes and at the B, M/30, and E fulfillment levels. Those repeated appearances could challenge faculty to integrate creative thinking into the curricular and co- and extra-curricular components of their CE programs.

Having noted some of the pros and cons of the two approaches, recognize the possibility of using both of them for any of the elements in Table 1 thus generating a third way to include creativity/innovation in the CE BOK. In keeping with this paper's purpose ("suggest that the EBOK and ECM warrant attention because their intents and contents overlap with the CEBOK2"), I am neither compelled nor prepared to recommend how to integrate creative thinking or any other potential six new elements into the CEBOK. I recommend that means such as a new outcome, a theme, and/or both be considered along with the other ideas that may be generated.

Before closing the discussion of ways to reflect new elements in the next CEBOK, consider also eliminating some outcomes. For example, might the current sustainability outcome (Outcome 10) be omitted, as a separate outcome, with its intent and content rolled into the current design outcome (Outcome 9)? Such questions should be part of the next round of CEBOK discussions.

Summary of Key Ideas

This paper's purpose is to suggest that the EBOK and ECM warrant attention in the next round of CEBOK discussions because their intents and contents overlap with and could add value to the revised or new CEBOK. In accomplishing this purpose, the paper:

- Explained why the EBOK was developed and described its features.
- Explained why the ECM was developed and described its features.
- Identified seven capabilities/competencies in the EBOK and ECM that are not in the CEBOK2 and suggested that they be considered for inclusion in a revised or new CEBOK. The seven elements are: Client/Stakeholder Focus, Creative Thinking, Engineering Economics, Manufacturing and Construction, Operations and Maintenance, Quality Control and Quality Assurance, and Safety.
- Offered ideas, including new outcomes and/or a theme approach, on how those capabilities/competencies might be adapted to the CEBOK.

I hope that ASCE's Raise the Bar leaders and college of engineering leaders will find this paper's exploration of the relevance of the EBOK and the ECM useful as they embark on the update of the CEBOK along with continued use of it.

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Appendix A: Example Description of an EBOK Capability: 5. Design[1]

Description

Design, whether used as a verb to represent a process or interpreted as a noun to refer to the result of the process, is a core capability in engineering. As a process, design may be defined as fulfilling client, owner, or customer needs while also satisfying established regulations and codes and meeting the standard of care. Design is the means by which ideas become reality.

The design process -- the root of engineering -- begins with defining the problem and project requirements and is followed by collecting relevant data and information; logical thinking; applying scientific principles; developing alternatives; considering socioeconomic and environmental effects; assessing risk, reliability, operability, and operational safety; specifying quality assurance provisions; using judgment in all aspects; and formulating a plan of action. The final step in the design process is communicating the results in a manner that enables implementation through manufacturing, construction, or some other means.

Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process, often iterative, in which the basic sciences, mathematics and the engineering sciences are applied to convert resources optimally to meet these stated needs. The design process incorporates engineering standards and multiple realistic constraints.

While the design process typically relies heavily on proven means and methods, it may include innovative approaches. The goal of design is quality, that is, meeting all requirements such as meeting functional needs and staying within a budget. The ultimate result of the design process -- the fruit that grows from the root -- is an optimal solution consisting of a structure, facility, system, product, or process. More specifically, design leads to highly varied results such as automobiles, airports, chemical processes, computers and other electronic devices, nuclear power plants, prosthetic devices, skyscrapers, ships, and spacecraft.

Example Abilities

As examples of design capability, an engineer entering practice at the professional level should be able to:

- Identify, or work collaboratively to identify, the pertinent technical, environmental, economic, regulatory, and other project requirements and constraints;
- Gather information needed to fully understand the problem to be solved and to form the basis for the evaluation of alternatives and design;

- Contribute to the development of alternatives and prepare design details for complex projects;
- Analyze the pros and cons of some alternative design options and assist in the selection of an optimized design alternative;
- Analyze the constructability or manufacturing feasibility of a project or product;
- Design a basic facility, structure, system, product, or process to meet well-defined requirements; and
- Apply lessons learned from other design projects.
