

AC 2010-1584: A BODY OF KNOWLEDGE FOR THE CONSTRUCTION ENGINEERING AND MANAGEMENT DISCIPLINE

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A Body of Knowledge for the Construction Engineering and Management Discipline

Abstract

Many engineering professional associations and societies have defined the body of knowledge (BOK) related to their specific engineering disciplines to define the knowledge, skills, and attitudes necessary to become licensed and/or certified to practice professionally. Educators can use such BOKs to identify the knowledge domain for undergraduate and graduate degree programs. A construction engineering and management BOK has not been previously established. As part of a longitudinal review of the construction curriculum, a BOK regarding the technical aspects of construction management has been defined based on a review of the requirements of multiple accrediting bodies. Four principal knowledge areas (cost estimating, construction scheduling and control, project administration, and contract documents) were identified as representing particular sectors of construction management for which there is a set of knowledge and skills. A process for defining program outcomes based on the BOK and course learning objectives based on program outcomes, and mapped back to the BOK, is presented. The BOK and the curriculum development process are independent of any accreditation body, which allows both to be used by any CM program regardless of current or future accreditation requirements.

Introduction

The phrase *body of knowledge* (BOK) is often used to refer to a set of concepts and methods within the domain of a subject. Within the engineering profession, the professional associations and societies have defined the BOK related to the specific engineering disciplines.^{1,2,3,4,5,6} The BOKs for the engineering disciplines have been developed to define the knowledge, skills, and attitudes necessary to become licensed and/or certified to practice professionally within the discipline. The American Society of Civil Engineers (ASCE) developed a BOK related to civil engineering and defined it as “the necessary depth and breadth of knowledge, skills, and attitudes required of an individual entering the practice of civil engineering in the 21st century”.⁷ The Environmental Engineering BOK⁸ authored by the American Academy of Environmental Engineers (AAEE) is described as “the knowledge and core competencies integral to the understanding and practice of environmental engineering”. Other engineering focused BOKs can be described in a similar manner.

As a result of engineering BOKs developed to reflect necessary knowledge and abilities, engineering educators have looked to the BOKs when developing and defining curricula. The Computer Engineering BOK⁹ authored by the IEEE Computer Society is specifically defined as “the knowledge domain that is likely to appear in an undergraduate curriculum in computer engineering”. Curricula are not based solely on a defined BOK, but are also developed to conform to requirements established by degree accreditation bodies such as ABET.

To date, no construction related professional society has defined a BOK specific to the practice of construction engineering and management. Thus, programs awarding degrees in construction

engineering (ConE), construction engineering and management (CEM), and construction management (CM) have developed curricula largely based only on requirements for accreditation. The faculty of the CM program at the University of North Carolina at Charlotte (UNC Charlotte) performed a longitudinal review of its construction curriculum, and in the process defined a potential BOK regarding the technical aspects of construction management.

The CM degree at UNC Charlotte is not currently accredited and thus is not limited by the requirements established by any single accrediting body. This allowed the faculty to consider the requirements of multiple accrediting bodies and synthesize these with recommendations based on the experiences of industry professionals. Accreditation requirements established by ABET, the American Council for Construction Education (ACCE), and the Chartered Institute of Building (CIOB) were all considered.

Based on the developed BOK, program outcomes were developed to drive the curriculum, and course learning objectives were created as a basis for assessment of the program outcomes and continuous improvement.

Construction Accreditation

The two principle accrediting bodies for construction education programs in the United States are ABET and ACCE. The CIOB provides accreditation of international programs in the United Kingdom and elsewhere throughout the world. The Engineering Accreditation Commission (EAC) of ABET accredits programs in construction engineering and the Technology Accreditation Commission (TAC) accredits programs in construction engineering technology. Construction management programs are largely accredited by ACCE. The CIOB accredits undergraduate and graduate programs in construction management, as well as design and commercial management.

The ABET accreditation process, either through EAC or TAC, is based on demonstrating student outcomes. In addition to general outcome criteria prescribed for all engineering related baccalaureate programs, construction related programs must also demonstrate achievement of outcomes specific to construction. The ABET EAC accreditation requires construction engineering programs to demonstrate that graduates have:

- proficiency in mathematics through differential and integral calculus, probability and statistics, general chemistry, and calculus-based physics
- proficiency in engineering design in a construction engineering specialty field
- understanding of legal and professional practice issues related to the construction industry
- understanding of construction processes, communications, methods, materials, systems, equipment, planning, scheduling, safety, cost analysis, and cost control
- understanding of management topics such as economics, business, accounting, law, statistics, ethics, leadership, decision and optimization methods, process analysis and design, engineering economics, engineering management, safety, and cost engineering.¹⁰

Baccalaureate degree programs in construction engineering technology accredited by ABET TAC must demonstrate that graduates are capable of:

- utilizing modern instruments, methods and techniques to implement construction contracts, documents, and codes;
- evaluating materials and methods for construction projects;
- utilizing modern surveying methods for construction layout;
- determining forces and stresses in elementary structural systems;
- estimating material quantities and costs;
- employing productivity software to solve technical problems;
- producing and utilizing design, construction, and operations documents;
- performing economic analyses and cost estimates related to design, construction, and maintenance of systems in the construction technical specialties;
- selecting appropriate construction materials and practices;
- applying principles of construction law and ethics;
- applying basic technical concepts to the solution of construction problems involving hydraulics and hydrology, geotechnics, structures, construction scheduling and management, and construction safety; and
- performing standard analysis and design in at least one recognized technical specialty within construction engineering technology that is appropriate to the goals of the program.¹¹

Unlike the outcome based focus of ABET, ACCE accreditation relies on a content based process that requires programs to provide a prescribed amount of instruction in five curriculum categories:

1. General Education	15 semester hours
2. Mathematics and Science	15 semester hours
3. Business and Management	18 semester hours
4. Construction Science	20 semester hours
5. Construction	20 semester hours ¹²

The required instructional time for each category is further enumerated, but only the details of the Construction Science and Construction categories are of interest here. Compliance with the requirements regarding the Construction Science category requires instruction in the following core subject matters:

1. Design Theory	3 semester hours
2. Analysis and Design of Construction Systems	6 semester hours
3. Construction Methods and Materials	6 semester hours
4. Construction Graphics	3 semester hours
5. Construction Surveying	3 semester hours ¹³

Compliance with the requirements regarding the Construction category requires instruction in the following core subject matters:

1. Estimating	3 semester hours
2. Planning and Scheduling	3 semester hours
3. Construction Accounting and Finance	1 semester hour
4. Construction Law	1 semester hour
5. Safety	1 semester hour
6. Project Management	3 semester hours ¹⁴

Fundamental topical content has been defined for each core subject area that must be included in the curriculum. However, the location and extent of instruction is at the discretion of the program.

The CIOB Educational Framework¹⁵ is based on learning outcomes structured in three levels:

1. Principles and Context
2. Analysis and Application
3. Synthesis and Evaluation

Each level is comprised of four components:

1. Construction Technology
2. Construction Environment
3. Specialism
4. Skills

The CIOB accredits programs for a first degree (undergraduate) in commercial, construction, design, and property management. The learning outcomes for most of the components at the first and second levels are common across the four degrees. Of particular interest for defining the construction management BOK were the outcomes for Level III – Construction Environment and all levels of Specialism. The prescribed outcomes of interest are:

- Level I – Specialism
 - To demonstrate an understanding of the operation of a construction company
 - To understand and use project planning techniques.
 - To demonstrate an understanding of what are safe sites and to be able to review the site planning process
 - To demonstrate an understanding of human resource management.
 - To review the selection and utilization of site plant and equipment.
- Level II – Specialism
 - Demonstrate an ability to analyse and apply the key elements of the construction process to project needs and case studies
 - Demonstrate an ability to analyse and apply construction finance management
 - Demonstrate an understanding of management in construction
 - Demonstrate an understanding and use of site costs and measurement
- Level III – Specialism
 - Demonstrate further understanding of management in construction
 - Demonstrate further understanding of contractual procedures
 - Demonstrate and apply project planning and programming skills
 - Demonstrate site management skills
- Level III – Construction Environment
 - To demonstrate a critical approach to project and site management skills through team work and continuous improvement
 - To apply and review health and safety management systems

While some of the construction accreditation programs reviewed are based on outcomes and others are based on instructional prescriptions, there is a great deal of commonality amongst the requirements. These areas of commonality allow knowledge areas to be defined for construction educational programs.

Construction Knowledge Areas

Based on the review of the accreditation requirements for construction programs, four principal areas of construction knowledge were identified to define the construction management BOK. Each knowledge area represents a particular sector of construction management for which there is a set of knowledge and skills. The four knowledge areas are: cost estimating, construction scheduling and control, project administration, and contract documents.

- I. The knowledge and skills associated with cost estimating include:
 - a. understanding the requirements of the work based on the drawings and specifications;
 - b. estimating work quantities;
 - c. evaluating and selecting appropriate construction means and methods;
 - d. estimating labor and equipment rates;
 - e. designing field operations and estimating rates of production;
 - f. estimating indirect and overhead costs; and
 - g. preparing a bid estimate.
- II. The knowledge and skills associated with construction scheduling and control include:
 - a. understanding and preparing various types of construction schedules;
 - b. developing a work breakdown structure and list of schedule activities;
 - c. planning an appropriate sequence activities for a logical project work flow;
 - d. estimating activity durations;
 - e. applying appropriate methods to allocate and level schedule resources; and
 - f. analyzing a project schedule and reporting project status
- III. The knowledge and skills associated with project administration include:
 - a. understanding project delivery processes;
 - b. applying principles of construction law and ethics;
 - c. understanding contractor licensing requirements and procedures;
 - d. understanding lien and labor laws as applied to construction;
 - e. identifying appropriate construction codes and regulations;
 - f. developing quality control programs and plans;
 - g. performing economic analyses and developing cash flow projections; and
 - h. managing risks on a construction project.
- IV. The knowledge and skills associated with contract documents include:
 - a. understanding the elements of a construction contract;
 - b. understanding payment, performance, and bid bonds;
 - c. preparing construction contract documents;
 - d. developing safety programs and plans; and
 - e. developing procurement documents for construction materials and services.

Collectively these knowledge areas and the identified knowledge and skills represent a BOK for entry level construction managers that should be acquired through undergraduate courses focused on construction. Additional knowledge and skills related to general education, mathematics and science, engineering fundamentals, and business management are appropriate for entry level construction managers, but are typically acquired through the completion of courses not focused on construction.

Construction Management Program Outcomes

The developed BOK was used to define a set of program outcomes that can be used to develop the curriculum, assess the program, and provide a datum for continuous improvement. The CM program at UNC Charlotte is housed within a department with other programs that are ABET TAC accredited, including a sister program in civil engineering technology. To maintain consistency between the programs and within the department, program outcomes were developed by adapting the BOK to an ABET specific format. Six program outcomes were developed:

1. Utilize appropriate tools to acquire data, analyze problems, and design a system or process.
2. Demonstrate effective skills in the development and presentation of team projects.
3. Exhibit knowledge and skills consistent with the expectations of a practicing construction manager.
4. Articulate the viability of creative and realistic solutions to defined problems and projects.
5. Recognize the value of diversity and identify ethical and societal issues in business and technical tasks.
6. Solve complex problems utilizing discipline specific expertise:
 - i. Utilize graphical techniques to produce engineering documents.
 - ii. Conduct standardized field and laboratory testing on civil engineering and construction materials.
 - iii. Utilize modern surveying methods for land measurement and/or construction layout.
 - iv. Determine forces and stresses in elementary structural systems.
 - v. Estimate material quantities for technical projects.
 - vi. Employ productivity software to solve technical problems.
 - vii. Produce and utilize design, construction, and project administration documents.
 - viii. Evaluate, select, and utilize appropriate construction procurement processes.
 - ix. Perform economic analyses and cost estimates related to the design, construction, and maintenance of systems found in construction.
 - x. Develop and utilize project schedules to analyze and control construction.
 - xi. Select appropriate construction materials, means, and methods.
 - xii. Apply principles of construction law and ethics.
 - xiii. Apply principles of business, quality, and management to construction practices.
 - xiv. Interpret and apply regulations and codes to ensure the health, safety, and welfare of construction personnel and the public.
 - xv. Evaluate sustainability concepts for green construction.

- xvi. Apply basic technical concepts to the solution of construction problems involving soil mechanics, foundations, structures, and building systems.

Program outcomes 1 through 5 address the required ABET outcomes (a) through (k), while outcome 6 addresses outcomes specific to the construction discipline. It was this construction specific outcome that was developed in ABET format to reflect the set of skills and knowledge outlined in the BOK. The sub-outcomes 6.i to 6.xvi were mapped to the BOK to demonstrate that they adequately represented the BOK, as shown in Table 1.

Construction Courses and Learning Objectives

The next step in the curriculum development process was to determine the contribution of each course within the CM program to meeting the defined program outcomes. Each course was mapped to the outcomes to identify specific content to be incorporated into the course. As an example, the CMET 3224 – Construction Project Administration and CMET 4126 – Project Scheduling and Control courses were mapped to the construction specific outcomes as shown in Table 2.

Specific learning objectives for each course were developed based on the program outcomes targeted by the course. The learning objectives were developed to reflect the skills and knowledge outlined in the developed BOK. This allowed each learning objective to be mapped to both the program outcomes and the BOK. Learning objectives for the CMET 3224 and CMET 4126 courses are provided and mapped to the outcomes and BOK in Tables 3 and 4, respectively.

Table 1: Construction Specific Program Outcomes Mapped to BOK

	Cost Estimating							Scheduling and Control						Project Administration								Contract Documents				
	a	b	c	d	e	f	g	a	b	c	d	e	f	a	b	c	d	e	f	g	h	a	b	c	d	e
Utilize graphical techniques to produce engineering documents.	X							X																X		
Conduct standardized field and laboratory testing on civil engineering and construction materials.																			X							X
Utilize modern surveying methods for land measurement and/or construction layout.		X																								
Determine forces and stresses in elementary structural systems.					X																					
Estimate material quantities for technical projects.		X									X															
Employ productivity software to solve technical problems.				X	X	X	X	X			X								X					X		
Produce and utilize design, construction, and project administration documents.							X	X										X	X	X				X	X	X
Evaluate, select, and utilize appropriate construction procurement processes.							X							X				X					X			
Perform economic analyses and cost estimates related to the design, construction, and maintenance of systems found in construction.			X	X	X	X	X												X	X						X
Develop and utilize project schedules to analyze and control construction.								X	X	X	X	X	X													
Select appropriate construction materials, means, and methods.			X																X		X					
Apply principles of construction law and ethics.															X	X	X	X			X				X	
Apply principles of business, quality, and management to construction practices.			X			X								X					X	X	X					
Interpret and apply regulations and codes to ensure the health, safety, and welfare of construction personnel and the public.					X										X			X	X		X				X	
Evaluate sustainability concepts for green construction.			X	X						X									X		X					
Apply basic technical concepts to the solution of construction problems involving soil mechanics, foundations, structures, and building systems.																										

Table 2: Construction Management Courses Mapped to Program Outcomes

		CMET 3224: Construction Project Administration	CMET 4126: Project Scheduling and Control
6.i	Utilize graphical techniques to produce engineering documents.		
6.ii	Conduct standardized field and laboratory testing on civil engineering and construction materials.		
6.iii	Utilize modern surveying methods for land measurement and/or construction layout.		
6.iv	Determine forces and stresses in elementary structural systems.		
6.v	Estimate material quantities for technical projects.		
6.vi	Employ productivity software to solve technical problems.	X	X
6.vii	Produce and utilize design, construction, and project administration documents.	X	X
6.viii	Evaluate, select, and utilize appropriate construction procurement processes.	X	
6.ix	Perform economic analyses and cost estimates related to the design, construction, and maintenance of systems found in construction.	X	
6.x	Develop and utilize project schedules to analyze and control construction.	X	X
6.xi	Select appropriate construction materials, means, and methods.		
6.xii	Apply principles of construction law and ethics.	X	
6.xiii	Apply principles of business, quality, and management to construction practices.		X
6.xiv	Interpret and apply regulations and codes to ensure the health, safety, and welfare of construction personnel and the public.		
6.xvi	Evaluate sustainability concepts for green construction.		
6.xvi	Apply basic technical concepts to the solution of construction problems involving soil mechanics, foundations, structures, and building systems.		

Table 3: Learning Objectives for CMET 3224 – Construction Project Administration

Course Learning Objective	Program Outcome	Construction BOK
Describe the basic project delivery processes in engineering and construction	6.viii	II.a
Identify the essential elements of a construction contract	6.vii	IV.a
Prepare a contract for a simple construction project	6.vii	IV.c
Estimate the cost of a conceptual project design	6.ix	III.g
Produce and analyze Gantt, CPM, and linear schedules	6.x	II.a
Use industry software to aid in preparing comprehensive construction schedules	6.vi	II.a
Analyze a construction claim and employ dispute resolution techniques	6.xii	III.b
Apply ethical principles to an engineering situation	6.xii	III.b

Table 4: Learning Objectives for CMET 4126 –Project Scheduling and Control

Course Learning Objective	Program Outcome	Construction BOK
Develop a WBS and list of schedule activities, sequence activities for a logical project work flow and estimate activity durations	6.vi	II.b II.c II.d
Develop a commodity loaded schedule using a commercially available scheduling software program	6.x 6.viii	II.a
Update a schedule and report project status in terms of schedule and cost criteria	6.x	II.f
Apply the serial and parallel methods for resource allocation	6.x	II.e
Apply the minimum moment algorithm to level resources	6.x 6.xiii	II.e
Develop a least cost crash curve for a schedule network	6.xiii	II.a
Quantify the time impact of a schedule change	6.x	II.f

Summary

A construction management BOK has been defined based on a review of the accreditation requirements for construction education programs prescribed by the EAC and TAC of ABET, ACCE, and CIOB. Four knowledge areas, cost estimating, construction scheduling and control, project administration, and contract documents, have been identified to represent the set of knowledge and skills related to construction management for entry level practitioners. This BOK describing the technical knowledge and skills required for entry level construction managers benefits construction educators by defining a significant portion of the knowledge domain for an undergraduate curriculum in construction engineering, construction engineering and management, and construction management.

Construction management faculty at UNC Charlotte have developed and followed a process for defining the CM program outcomes based on the BOK. The BOK and the curriculum development process are independent of any accreditation body, which allows both to be used by any CM program regardless of current or future accreditation requirements.

Bibliography

1. ASCE (2008). "Civil Engineering Body of Knowledge for the 21st Century – Preparing the Civil Engineer for the Future." 2nd ed., ASCE, Reston, VA.
2. AAEE Environmental Engineering Body of Knowledge Working Group (2008). "Environmental Engineering body of Knowledge: Summary Report." *Environmental Engineer: Applied Research and Practice*, v 6, Summer 2008, 21-33.
3. IEEE Computer Society (2004). "Guide to the Software Engineering Body of Knowledge: 2004 Version." P. Bourque, R. Dupuis, A. Abran, J. Moore, and L. Tripp, eds., IEEE Computer Society, Los Alamitos, CA.
4. American Academy of Water Resource Engineers (AAWRE) (2005). "Body of Knowledge for Water Resources Engineering." AAWRE, Reston, VA.
5. Ibid.
6. ASME (2009). "The Engineering Management Certification Body of Knowledge (EMC-BOK™)" <http://www.engineeringcertification.org/EMCBOK.cfm>, 8Jan10.
7. ASCE (2008). "Civil Engineering Body of Knowledge for the 21st Century – Preparing the Civil Engineer for the Future." 2nd ed., ASCE, Reston, VA.
8. AAEE Environmental Engineering Body of Knowledge Working Group (2008). "Environmental Engineering body of Knowledge: Summary Report." *Environmental Engineer: Applied Research and Practice*, v 6, Summer 2008, 21-33.
9. IEEE Computer Society Joint Task Force on Computer Engineering Curricula (2004). "Curriculum Guidelines for Undergraduate Degree Programs in Computer Engineering." IEEE Computer Society, Los Alamitos, CA.
10. ABET Engineering Accreditation Commission (2007). "Criteria for Accrediting Engineering Programs." ABET, Baltimore, MD.
11. ABET Technology Accreditation Commission (2007). "Criteria for Accrediting Engineering Technology Programs." ABET, Baltimore, MD.
12. ACCE (2006). "Standards and Criteria for Accreditation of Postsecondary Construction Education Degree Programs." Document 103, ACCE, San Antonio, TX.
13. Ibid.
14. Ibid.
15. Chartered Institute of Building (CIOB) (2007). "The CIOB Education Framework 2007." CIOB, Ascot, Berkshire, UK.