AC 2007-950: AN ASPIRATIONAL VISION FOR CIVIL ENGINEERING IN 2025: THE BOK AND FUTURE DIRECTIONS FOR CIVIL ENGINEERING CURRICULA

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An Aspirational Vision of Civil Engineering in 2025: the BOK and Future Directions for Civil Engineering Curricula[1]

Introduction

The report entitled *Civil Engineering Body of Knowledge* was published by the American Society of Civil Engineers (ASCE) in January 2004. This report, which is generally referred to as the BOK report, outlined the fundamental knowledge, skills and attitudes necessary for the practice of civil engineering at the professional level in the 21st century. This report by ASCE is consistent with the report entitled *The Engineer of 2020* prepared by the National Academy of Engineers (NAE) in 2004. As stated by the NAE, the engineers in 2020 will need more technical and business practice skills than are currently expected of engineers today. These reports are forward looking in that they have tried to articulate that which will be needed in the future if civil engineers are to continue having the significant impact on society and public welfare that they have in the past. For reference, the outcomes specified by ASCE are presented in Appendix I.

Part of the knowledge, skills, and attitudes outlined by ASCE are obtained through formal structured education, and other parts are obtained through focused professional experience after graduation. The Curriculum Committee of the Committee on Academic Prerequisites for Professional Practice (CAP^3) was charged with two fundamental tasks regarding the formal education component, namely:

- Determine the current status of civil engineering education in relation to the formal educational component of the BOK, and
- Determine the nature of change necessary to support the formal educational expectations of the BOK.

Presented in this paper is an extended summary of the work of the committee. The primary topics addressed in the paper are:

- The current status of civil engineering degree programs in relation to the ASCE BOK and a means to assess that status at an individual institution,
- Strategies for implementing the ASCE BOK into an institution's civil engineering degree programs at comprehensive doctoral institutions as well as undergraduate focused institutions, and
- A methodology for the assessment of BOK-compliant civil engineering degree programs.

Further, this paper provides ideas for institutions in implementing an ASCE-BOK compliant curriculum. It is not intended to provide a single model, or the way it should be done. Rather it is

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[1] This paper is extracted from the ASCE report *Development of Civil Engineering Curricula Supporting the Body of Knowledge for Professional Practice*, 2006.

to provide thoughts and strategies for institutions when they implement their own unique compliant programs.

FUNDAMENTAL ASSUMPTIONS

As the committee conducted its tasks, several assumptions were made about the nature of civil engineering curricula to focus the process and to provide boundaries within which the committee could have an impact on the overall development of a civil engineer. These assumptions also provided the philosophy by which the curricula would be developed. Discussed below are the primary assumptions made by the committee and the rationale for those assumptions.

Curriculum as a System

The fundamental approach to which the committee adhered is that a civil engineering curriculum is an engineered system designed to achieve a specified end and that it is tied directly to the desired program outcomes. The curriculum should reflect the complete educational experience of a student at a respective institution. That experience includes formal coursework as well as activities and professional development outside the classroom.

Taking a systems view of any process necessarily involves addressing such components as raw materials, the supply chain, production modes, distribution, and customer needs. It also entails understanding whatever assessment and feedback are present in the system. These principles can be applied to civil engineering curriculum design. Beginning with the “supply” of raw intellectual talent (i.e., students) provided from a variety of sources (e.g., high schools, community colleges, etc.), the educational system “produces” civil engineering graduates, which are then “distributed” to the workforce or to post-graduate education. The “need” driving the system is the ability to plan, lead, and execute civil engineering design, and the “customers” are public employers, private companies, nonprofit organizations, graduate programs, and the public-at-large. The systems view of civil engineering education thus takes into account entering students, potential students, BSCE graduates, educators, industry, government (employers and regulators), and the public-at-large—the stakeholders for civil engineering leadership, management, and design.[2]

The production part of the process is the civil engineering curriculum. In terms of “production,” the focus of the future system will shift from the BSCE degree to fulfillment of a body of knowledge deemed necessary for professional practice. This shift of focus necessitates a move from completion of courses to the assimilation of the knowledge, skills and attitudes necessary for professional practice. Corresponding to the shift from completing courses to assimilating a body of knowledge is a shift in assessment of course knowledge to the ability to perform and be responsible for civil engineering design. These changes in focus enable educational development to occur outside the classroom and the means to assess overall ability in design.

[2] Russell, Jeffrey S., *et al.*, “A Systems View of Changing Civil Engineering Education,” ASCE, September 2003.

Undergraduate versus Graduate Emphasis

As development of curricula supporting ASCE Policy Statement PS 465 and the civil engineering BOK began, two questions immediately arose. Those two questions were:

- What should be addressed predominantly at the undergraduate level and what should be addressed predominantly at the graduate level?
- How will completion of the BOK be assured if a student completes undergraduate study at one institution and then pursues graduate study at another institution?

The answer to these questions—the direction taken in curriculum design—can have a significant impact on the structuring of the curricula itself and on accreditation criteria developed that support completion of the BOK. As such, agreement had to be reached regarding a fundamental philosophy of curriculum development.

If there is not consistency in expectation at the undergraduate and graduate level among institutions, a student pursuing graduate study at an institution different from that at which he or she pursued undergraduate study may or may not have the same background as undergraduates from the graduate institution. The underlying issue is who would be responsible for "validating" attainment of the BOK. Further, the structuring of accreditation criteria would be difficult as programs are currently accredited at either the basic level or the advanced level.

To address these concerns, the committee agreed that all outcomes of the BOK, except outcome 12 can be achieved at the undergraduate level. The expectations of outcome 12 are beyond that which is reasonably included in an undergraduate curriculum and can be expected of undergraduate students. The other 14 outcomes, to the level of achievement expected in the BOK, can be fulfilled at the undergraduate level. Although expected to be fulfilled at the undergraduate level, the other outcomes can and should be reinforced at the graduate level. The reader should note that the levels of achievement stated in the BOK document (recognition, understanding, and ability) were modified. The modified levels of achievement were based on Blooms Taxonomy, which defines six levels in the cognitive domain: knowledge, comprehension, application, analysis, synthesis, and evaluation.

Education Outside the Classroom

The committee recognized that a significant part of a student's education and the corresponding development of the knowledge, skills and attitudes for professional development occurs outside the classroom. Co-curricular activities, such as participation in the functions of the ASCE student chapter and participation in on-campus professional development activities, can be used to achieve the BOK to the level expected. As curricula are developed, means should be incorporated to include these co-curricular activities as a part of the education "system" developed. Incorporation of required co-curricular activities will have an impact on assessment of a student's learning.

Enable Uniqueness and Flexibility

Each educational institution and each civil engineering program is unique. As possible curricula supporting the BOK were developed, the intention was to maximize institutional choice in fulfilling the BOK and to enable each program to maintain its unique characteristics. The minimum curriculum design objective is specified through the expected outcomes and levels of achievement defined in the BOK. The intention of the curriculum design committee is to provide means and examples of how to develop a BOK compliant curriculum; the intention is not to prescribe a curriculum that must be implemented.

EVALUATION OF CURRENT CURRICULA

Prior to making change to a civil engineering curriculum to "incorporate" the BOK, an institution must evaluate the status of its current curriculum in relation to the outcomes and level of achievement defined in the BOK. This process involves four steps: 1) Establishing a method for evaluation, 2) Identifying the current program strengths, 3) Identifying areas of needed program improvement, and 4) Determining the steps necessary to attain the BOK while enhancing the program's strengths and addressing the areas of needed improvement. During this process, as previously discussed, the curriculum must be evaluated as an engineered system and not as a collection of courses. Components of the system are curricular activities that occur within the structured classroom environment and those required co-curricular activities that occur outside the classroom.

Evaluation of the current compliance of a civil engineering program with the levels of achievement specified in the BOK must consider the entire required academic experience of the student; the program must be viewed and evaluated as a system, a system that includes curricular and may include co-curricular activities. During the evaluation, faculty should recognize that achievement of the required level is not necessarily attained in a single course or through a single activity. Attainment of a level of achievement can, and often does, occur through a cumulative set of activities across many experiences in the program.

The evaluation of the curriculum should be conducted within the context of the six levels of Bloom's taxonomy. Bloom's levels of cognitive development provide a starting point for outcome evaluation. A rubric indicating possible expectations at each level for each outcome is presented in Appendix F of the full report. This rubric was developed to facilitate program evaluation by specifying verbs describing the actions of graduates that can be expected at each level. The quantity and quality of course activities should be considered when establishing the final Bloom's level accomplished in each course and for each required co-curricular activity.

The overall assessment for a given outcome may include specific activities outside of the classroom that every student is required to complete such as summer internship and co-op programs, intramurals, military science courses, ASCE student chapter activities, the Fundamentals of Engineering (FE) Examination review sessions, etc. The level of achievement of a particular activity should not be confused with the level of achievement for the program outcome. For example, if the coverage of activities at level 5 is limited and there are numerous activities in a number of courses at level 4, then it is reasonable for the program to assume that it only achieved level 4. Assessment based on activities accomplished in each course enables a program to realistically determine where they need to increase the activity level to meet a certain Bloom's level and where they might be able to reduce some of the activities to make room for other required activities.

UNDERGRADUATE CURRICULA

Current Status—Graduate Focused Programs

Today, the educational mission at institutions with comprehensive doctoral programs is predominantly focused at the PhD level with Master's degrees being considered as a step toward attainment of the PhD. Although they provide high-quality undergraduate programs of study, their mission, though, is heavily oriented toward research, which naturally makes use of doctoral candidates. A civil engineering program at a comprehensive doctoral institution will ordinarily have the following characteristics:

- Faculty at comprehensive doctoral institutions can be segregated into three distinct groups: those who principally teach at the undergraduate level, those who conduct research and teach at the graduate level, and those who teach very little and whose primary function within the program is to conduct sponsored research.
- Graduate-focused universities tend to be older established institutions with long histories of recognized excellence in the academic community.
- The history of these institutions generally indicates that they earned their reputations for educating engineers at the undergraduate level; research emphasis ordinarily came later as the programs developed, and as scientific and technological advances dictated the need for more research within the academic community.
- Comprehensive doctoral programs usually have considerably larger and more comprehensive laboratory facilities.
- Many of comprehensive doctoral programs actively engage undergraduates involvement in research
- Undergraduate class sections at comprehensive doctoral institutions tend to be larger.

The undergraduate program at a comprehensive doctoral institution is subjected to the same accreditation requirements as the predominantly undergraduate institutions. With the limited number of credit hours now considered sufficient for an undergraduate civil engineering degree (128 in most cases), there appears to be little flexibility in providing creative opportunities within the confines of the ABET mandates whether at a predominantly undergraduate program or at a comprehensive doctoral program. Therefore, the undergraduate curricula are quite similar to that identified with undergraduate-focused programs. A "typical" curriculum at a comprehensive doctoral institution is characterized by:

- A 4-year (8 semesters) academic program leading to a B.S. in Civil Engineering degree
- A broad education in civil engineering covering at least 4 of the major sub-disciplines within civil engineering
- Composed of distinct, individual courses
- Supportive of co-operative education and summer internship programs
- Supportive of student participation in clubs and professional organization student chapters, e.g. ASCE and Chi Epsilon.

One method to characterize a curriculum is to identify the number of courses that address a specific BOK outcome. Although this is not necessarily indicative of the level of achievement attained for a particular outcome, it does provide a metric indicating the fraction of a curriculum allocated to each outcome. For a typical curriculum at a comprehensive doctoral institution this allocation is presented in Table 1.

Table 1—Number of courses addressing each BOK outcome

BOK Outcome	Number of Courses
1. Mathematics, Science & Engineering	30
2. Experiments, Analyze, and Interpret	13
3. Ability to Design a System	16
4. Multi-Disciplinary Teams	8
5. Solve Engineering Problems	23
6. Professional & Ethical Responsibility	10
7. Communicate	13
8. Impact of Engineering Solutions	13
9. Lifelong Learning	13
10. Knowledge of Contemporary Issues	13
11. Modern Engineering Tools	13
12. Knowledge in a Specialized Area	3
13. Elements of Project Management	5
14. Business and Public Policy	4
15. Leadership and Role of the Leader	4

Current Status—Undergraduate Focused Programs

Predominant undergraduate focused engineering programs have as their primary mission the education of undergraduate civil engineering students. A civil engineering program, then, at a predominantly undergraduate institution will typically have the following characteristics:

- No graduate program or a limited Master's program
- Smaller enrollments and fewer faculty, and the faculty are principally engaged in teaching
- Fewer course offerings both in number and breadth

A "typical" curriculum at a predominantly undergraduate institution is characterized as being:

- A 4-year (8 semesters) academic program leading to a B.S. Civil Engineering degree
- A broad education in civil engineering covering at least 4 of the major sub-disciplines within civil engineering
- Composed of distinct, individual courses
- Supportive co-operative education and summer internship programs
- Supportive of student participation in clubs and professional organization student chapters, e.g. ASCE and Chi Epsilon.

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The typical curriculum is composed of 126 semester hours (40 courses) divided among six content areas: math and science (25% of total hours), engineering science (12%), engineering fundamentals (8%), engineering (31%), professional (10%), and humanities and social sciences (14%). For a typical curriculum at a predominantly undergraduate institution the allocation of courses among the BOK outcomes is presented in Table 2

Table 2—Number of courses addressing each BOK outcome

BOK Outcome	Number of Courses
1. Mathematics Science & Engineering	26
2. Experiments, Analyze, and Interpret	9
3. Ability to Design a System	14
4. Multi-Disciplinary Teams	5
5. Solve Engineering Problems	19
6. Professional & Ethical Responsibility	9
7. Communicate	12
8. Impact of Engineering Solutions	8
9. Lifelong Learning	3
10. Knowledge of Contemporary Issues	9
11. Modern Engineering Tools	11
12. Knowledge in a Specialized Area	0
13. Elements of Project Management	3
14. Business and Public Policy	5
15. Leadership and Role of the Leader	5

An alternate breakdown of this information is presented in Appendix II. In that appendix, the various courses that comprise the curriculum are shown in relation to the outcomes that they can serve. Based on extensive discussions and data such as this, the committee concluded that all outcomes, except outcome 12, can be addressed in a typical undergraduate program composed of 125 to 130 credit hours.

Concluding Thoughts

The typical graduate-focused curriculum does not appear to be significantly different from the typical undergraduate-focused curriculum. If there are differences between these two distinct institutional focuses, then it does not appear to be significant within the offerings provided in the general undergraduate curricula. As such, the focus of the program is not expected to be a dominant driver as institutions revise their curricula to achieve the BOK outcomes to the level expected.

MISSING ELEMENTS

Need for Additional Science

When considering the explicit and implicit expectations of the Body of Knowledge, there appears to be need in most curricula for additional science. Predominantly, the curricula evaluated contain one course in chemistry and two courses in physics, and these do not provide much breadth relative to the science implicit in civil engineering as expected in the BOK. This seems to be inconsistent with the expectations of engineers in the 21st century as suggested in the

BOK. As such the committee recommends that an additional science elective be incorporated into the curriculum to provide greater depth or breadth in science, consistent with a student's personal education goals. The intention of this recommendation is not that a student takes an additional chemistry or physics course as follow-on to the courses already required. This additional science requirement could be satisfied as follows:

- After completing the typical introduction to chemistry, a student could choose an elective in physical chemistry or organic chemistry. Such an elective would be appropriate for students wishing to practice in the areas of environmental engineering or construction materials engineering.
- A student could take an introductory level course in Geology. This course should be one that is intended for science majors. It would support the areas of geotechnical engineering or environmental engineering within civil engineering.
- A student could take an introductory level course in the area of Biology. This course would provide additional breadth in science for students pursuing environmental engineering. The course taken should be one that is intended for science majors.

The need for additional science is not satisfied by simply taking the follow-on course to Chemistry I, or equivalent.

Advanced Technical Knowledge

The current undergraduate curricula examined all provided the technical breadth and depth expected for current ABET/EAC accreditation criteria. The extent of the technical depth provided in an area, such as structural engineering, varied from program to program, and depended upon the program focus. None of the curricula examined provided sufficient technical depth to achieve the specialized knowledge in an area of civil engineering to the level expected by the BOK. Further, with the additional outcomes that must be accomplished, the committee did not believe that the expectation for technical depth could be accommodated in the undergraduate program while at the same time accommodating the other outcomes. This is especially true with the continued trend in some states to reduce the number of credit hours permitted in an undergraduate degree program. For this reason, the committee recommends that the specialized technical knowledge outcome be achieved within the graduate program. The other outcomes, then, can be accommodated in an undergraduate degree program.

ASSESSMENT METHODOLOGIES

When formulating an assessment plan to determine whether a curriculum achieves the civil engineering Body of Knowledge, an institution can quickly be drawn toward assessment of the entire curriculum. Often times, the supporting data used as part of this program assessment is primarily collected through some type of survey instrument. Such an approach, in the opinion of the committee, has three weaknesses. These weaknesses are:

- Surveys provide an indirect and often subjective assessment of the curriculum. Further, the opinions reported in a survey are not necessarily indicative of the full program nor do they address all aspects of the program.
- From assessment of an entire curriculum, determining the root cause of a weakness can often be masked. That is to say, determining whether there are incorrect linkages

between courses, inconsistent teaching of courses, or a completely missed subject matter in the curriculum is often impossible to determine.

- Unless quantitative means can be provided to assess subject matter globally, determining long-term comprehension of critical material by the students in difficult, if not impossible.

To address these concerns and at the same time establish a robust and sustainable assessment program, a two-tiered approach to assessment of program outcomes is recommended. The approach recommended contains curriculum level assessment and course level assessment. Such an approach to assessment provides a quantitative means to evaluate assimilation of the requisite material by the students, ensures that necessary curriculum content is addressed and reinforced throughout the curriculum as appropriate, and that the necessary interactions and connections between courses exist.

Eventually, the formal assessment of BOK compliance will most likely be done in conjunction with ABET accreditation and assessment of program outcomes. ABET has been working hard to educate programs that relying on survey data alone is not acceptable. Data that supports internal assessment of whether a program is meeting established program outcomes needs to be collected through multiple sources. Course assessments are becoming popular as a viable source of data that is required to assess a program fully.

Course Continuity Assessment

For those schools that conduct course assessments, the observed processes vary greatly. In some cases, the instructor simply completes a page on how he/she felt the semester went and what might improve the next iteration of the course. Others focus on answering the results of the end-of-course web-based or mark-sense feedback provided by the students. Others use the course assessment as a systematic means to collect course data that can be consolidated for a program assessment. Generally, the process and comment is prepared by the course instructor and submitted to the program director for review and filing. The real question to be answered is what is the purpose of the course assessment and how can the program director maximize its use? Additionally, should the course assessment process involve more than the instructor teaching the course? Many courses feed into other courses and therefore have a direct impact on the entire program. Should all of the follow-on course instructors be present when course changes are discussed? At what point does this administration become too burdensome and therefore unsustainable? Many programs are wrestling with how to conduct quality course assessments.

The assessment collects information in a systematic and consistent manner to be analyzed annually by the program director as she assesses the overall program. The process also documents the course as it was taught during a given academic year, documents requested/desired/planned changes (based on coordination processes in a given program), the results of previous changes to a course, and shares good ideas among the entire faculty by including instructors from pre-requisite and follow-on courses. Detailed course documentation is extremely important when transferring a course on short notice to a different (usually new) faculty member and provides an available repository of course content and historical knowledge. Using a consistent format that requires the same information from each course provides a better picture for the program director concerning facilities, course/program/departmental policies, which course objectives feed directly into program outcomes, etc.

This assessment consists of three sections: course description, course assessment, and recommended changes. The recommended changes section is not an attempt to curtail academic freedom, but an effort to support controlled change in each course that is part of an overall program design. Each course is expected to cover required topics to allow students to build progressively toward their culminating capstone experience. Additionally, many courses are pre-requisites for others. An instructor who arbitrarily drops content and replaces it with another topic might be placing their students at a disadvantage in future years. Many faculty members are occasionally asked to teach a course outside their area of expertise. It is conceivable that they might drop content that is required in a follow-on course. The follow-on instructor needs to know this in advance. However, there is often little communication between faculty members concerning course content. Faculty must work as a team in designing a coherent engineering experience (program) for their students.

The course description section could cover course catalog description (does it reflect what is covered in the course), when the course is offered, enrollment numbers over a period of time, course objectives (different than course description, using active verbs to describe what a student should be able to do after completing the course), course textbook(s), course content by lesson (to include what course objectives are covered in what lessons), a summary of graded events and associated points, any additional information as directed by the program director (group work, special lessons, computer usage, facilities assessment, curriculum integration, course policies, and directed web-based questions).

The course assessment section could cover whether course objectives were achieved (student survey results versus instructor), other web-based feedback results (sometimes a majority of the questions are dictated at college or university level), instructor directed end-of course questions (web-based or hard copy in class), historical course quality point average, historical final exam averages, historical courses average, and course specific feedback (i.e., Capstone project summary). The results of this section can be consolidated with the results from other courses to assess the degree to which a program meets the BOK. The course assessment could also address relevant questions such as: do the course objectives cover the body of knowledge, are the objectives measurable, are the course processes appropriate, how the course contributes to accomplishment of the program outcomes, and were previous changes effective.

The last section covers recommended changes based on the assessment of the data collected during previous semesters and possible discussions with other instructors. Primary areas to consider for changes can include course objectives, textbook, course content, graded events, program directors areas of special emphasis (group work, special lessons, computer use, facilities assessment, course integration, embedded indicators, course policies, etc.)

Curriculum Level Assessment

Equally important to assessing that the curriculum as developed and implemented provides a coherent and complete presentation of the material to the students, the retention of that information by the students must be assessed. In particular, the retention and internalization by the students of the necessary content across the entire curriculum must be assessed. This assimilated information is that which is carried forward and is built upon in subsequent courses.

There are three primary methods for assessing student retention of the information conveyed. These methods are:

- Retention examinations at critical points in the program of study,
- An external jury review of the capstone design projects, and
- The Fundamentals of Engineering Examination.

Each of the means will be discussed briefly in the sections that follow.

Assimilation Examination

Assimilation assessment examinations of the students to determine the level to which they are assimilating the information needed at key points in the curriculum can be conducted. The content of these examinations is determined by the faculty and is based upon the individual program curriculum. The content of the examination is that information which the students should have at their command; the content is not everything taken in every course to that point. Through analysis of the results, progression toward completion of the BOK outcomes can be assessed. Further, programmatic weaknesses that affect student performance can be identified. If curricular presentation can be changed to improve retention when progressing through the program of study, overall achievement of the BOK will be facilitated.

There is a secondary benefit to these examinations. They can be formatted and conducted in a manner similar to the Fundamentals of Engineering Examination. By taking these examinations formatted in this manner during the program of study, students become comfortable with examination and will likely have better performance on the FE examination—familiarity brings a level of comfort which improves performance in general.

The target score on the examination and target performance by subject is something that must be determined by the faculty. It will vary somewhat from one institution to the next because program emphasis is different. These performance measures, however, can and should be tied back to the BOK outcomes.

Capstone Jury Review

The capstone design project is an excellent means to assess internalization of knowledge at the time of graduation and the ability to apply that knowledge. To be most effective, the capstone design projects should be reviewed by a jury dominated by practicing engineers. Presentation of the projects to the jury should include a written report that is presented orally to the jury and defended. To ensure that meaningful assessment is collected, there should be formal review sheet prepared that is completed by all members of the jury so that comment on specific program outcomes is sought.

Fundamentals of Engineering Examination

Considerable information has been written about using the Fundamentals of Engineering Examination as an assessment tool and will not be repeated here. The concept to be presented here, however, that completion of the FE examination by all students provides an excellent means to assess student assimilation of knowledge at the time of graduation as that examination, in principle, covers all aspects of a student's undergraduate education and is taken at the end of the educational process. Further, because performance on the examination is reported by subject area, analysis can be conducted to determine where curriculum improvement might be made to have the greatest impact on student learning and retention of knowledge, and on achievement of the BOK outcomes. To be used in this manner, however, all graduating students need to take the examination, unless the program can justify that the students taking the examination are statistically representative of the entire student population.

Another advantage of using the FE examination as a system assessment tool is that it is a nationally normed examination. Determining a reasonable level of performance at an individual institution is done as a comparison to a broad national population.

CONCLUSIONS AND RECOMMENDATIONS OF THE COMMITTEE

Several conclusions can be drawn from the work of the Curriculum Committee. First, the BOK as it currently exists is not accomplished within current civil engineering curricula. All programs considered accomplished outcomes 1-11 (essentially ABET outcomes a-k) to the level of achievement expected in the BOK. Individual programs accomplish the remaining four outcomes, those addressing specialized technical knowledge, business and public policy, business practice and asset management, and leadership, to a greater or lesser extent. None of the programs, however, addresses all of these outcomes to the level of achievement expected in the BOK.

Second, the committee concluded that the BOK, except for the outcome regarding technical specialization, can be included in the undergraduate curriculum. The means by which the outcomes are incorporated are many and do not need to be consistent from program to program. The means include required seminars, additional and redesigned courses, and enhancement of content in current courses.

The outcome regarding specialized technical knowledge is best accomplished in a post-graduate program of study. By not including technical specialization in the undergraduate program of study, necessary breadth can be achieved without increasing the size of the curriculum. Further, this approach facilitates program accreditation by delineating the content of the curricula—that which is expected to be accomplished at the undergraduate level and at the graduate level become consistent across curricula.

When considering the explicit and implicit expectations of the Body of Knowledge, there appears to be need in most curricula for additional science. Predominantly, the curricula evaluated contain one course in chemistry and two courses in physics, and these do not provide much breadth relative to the science implicit in civil engineering as expected in the BOK. As such the committee recommended that an additional science elective be incorporated into the curriculum.

APPENDIX I—CIVIL ENGINEERING BOK OUTCOMES

Following are the 15 outcomes in the current Civil Engineering Body of Knowledge for entry into professional practice. Included with each outcome is the commentary from the BOK.

1. **An ability to apply knowledge of mathematics, science, and engineering. (ABET a)**

   Commentary: A technical core of knowledge and breadth of coverage in mathematics, science and civil engineering topics is stressed in this outcome. Underlying the professional role of the civil engineer as the master integrator and technical leader are most of the following: mathematics through differential equations, probability and statistics, calculus-based physics, biology, chemistry, ecology, geology/geomorphology, engineering economics, mechanics, material properties, systems, geo-spatial representation, and information technology.

   Increased exposure to or emphasis on biological systems, ecology, sustainability, nanotechnology, and information technology is expected to occur in the 21st century. In imparting the common technical core, students should understand the fundamentals of several recognized major civil engineering areas. (Note: The portion of this commentary which states "students should understand the fundamentals of several recognized major civil engineering areas" differs from ABET Program Criteria for Civil and Similarly Named Engineering Programs[7] which calls for "proficiency in a minimum of four recognized major civil engineering areas.")

2. **An ability to design and conduct experiments, as well as analyze and interpret data. (ABET b)**

   Commentary: Civil engineers frequently design and conduct field and laboratory studies, gather data, create numerical and other models, and then analyze and interpret the results. Licensed civil engineers should be able to do this in at least one of the evolving or current major civil engineering areas. Examples are traffic, geotechnical, and water quality investigations.

3. **An ability to design a system, component, or process to meet desired needs. (ABET c)**

   Commentary: Critical design methodology and process elements include problem definition, scope, analysis, risk assessment, environmental impact statements, creativity, synthesizing alternatives, iteration, regulations, codes, safety, security, constructability, sustainability, and multiple objectives and various perspectives.

   Other important design or design procurement elements are bidding versus qualifications-based selection (QBS); estimating engineering costs; interaction between planning, design and construction; design review; owner-engineer relationships; and life-cycle assessment. Understanding large-scale systems is important, including the need to integrate information, organizations, people, processes, and technology. Design experiences should be integrated throughout the professional component of the curriculum.

4. **An ability to function on multi-disciplinary teams. (ABET d)**

   Commentary: Licensed civil engineers should be able to lead a design or other team as well as participate as a member of a team. This requires understanding team formation and evolution, personality profiles, team dynamics, collaboration among diverse disciplines, problem solving, and time management and being able to foster and integrate diversity of perspectives, knowledge, and experiences.

5. **An ability to identify, formulate and solve engineering problems. (ABET e)**

   Commentary: Assessing situations in order to identify engineering problems, formulate alternatives, and recommend feasible solutions is an important aspect of the professional responsibilities of a civil engineer.

6. **An understanding of professional and ethical responsibility. (ABET f)**

   Commentary: The civil engineer is to hold paramount public safety, health, and welfare. A thoughtful and careful weighing of alternatives when values conflict is crucial to the responsible conduct of engineering. Therefore, civil engineers practicing at the professional level need to demonstrate an understanding of and a commitment to practice according to the seven Fundamental Canons of Ethics and the associated Guidelines to Practice Under the Fundamental Canons of Ethics.

7. **An ability to communicate effectively. (ABET g)**

   Commentary: Effective communication includes listening, observing, reading, speaking, and writing and requires understanding of the fundamentals of interacting effectively with technical and nontechnical or lay individuals and audiences in a variety of settings. Professional civil engineers need to be versatile with mathematics, graphics, the worldwide web and other communication tools.

8. **The broad education necessary to understand the impact of engineering solutions in a global and societal context. (ABET h)**

   Commentary: Professional civil engineers need to appreciate, from historical and contemporary perspectives, culture, human and organizational behavior, aesthetics and ecology and their impacts on society including the history and heritage of the civil engineering profession.

9. **A recognition of the need for, and an ability to engage in, life-long learning. (ABET i)**

   Commentary: Life-long learning mechanisms available for personal and professional development include additional formal education, continuing education, professional practice experience, active involvement in professional societies, community service, coaching, mentoring, and other learning and growth activities.

   Personal and professional development can include developing understanding of and competence in goal setting, personal time management, communication, delegation, personality types, networking, leadership, the socio-political process, and effecting change.

   In addition to the preceding, professional development can include career management, increasing discipline knowledge, understanding business fundamentals, contributing to the profession, self-employment, additional graduate studies, and achieving licensure and specialty certification.

10. **A knowledge of contemporary issues. (ABET j)**

    Commentary: To be effective, professional civil engineers should appreciate the relationship of engineering to critical contemporary issues such as multicultural globalization of engineering practice; raising the quality of life around the globe; the growing diversity of society; and the technical, environmental, societal, political, legal, aesthetic, economic, and financial implications of engineering projects.

11. **An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (ABET k)**

    Commentary: This includes the role and use of appropriate information technology, contemporary analysis and design methods, and applicable design codes and standards as practical problem-solving tools to complement knowledge of fundamental concepts. Also included is the ability to select the appropriate tools for solving different types and levels of problems.

12. **An ability to apply knowledge in a specialized area related to civil engineering.**

    Commentary: For a professional civil engineer, specialized technical coursework (or the equivalent) is necessary. Examples of specialized technical areas include environmental engineering, structural engineering, construction engineering and management, public works management, transportation engineering and water resources management. Civil engineering specializations in non-traditional, boundary, or emerging fields such as ecological engineering and nano-technology are encouraged.

13. **An understanding of the elements of project management, construction, and asset management.**

    Commentary: Efforts of the professional civil engineer often lead, in the context of projects, to construction of structures, facilities and systems that, in turn, must be operated and maintained.

    Project management essentials include project manager responsibilities, defining and meeting client requirements, risk assessment and management, stakeholder identification and involvement, contract negotiation, project work plans, scope and deliverables, budget and schedule preparation and monitoring, interaction among engineering and other disciplines, quality assurance and quality control, and dispute resolution processes.

    Important construction elements are owner-engineer-contractor relationships; project delivery systems (e.g., design-bid-build, design-build); estimating construction costs; bidding by contractors; labor and labor management issues; and construction processes, methods, systems, equipment, planning, scheduling, safety, cost analysis and cost control.

    Asset management seeks effective and efficient long-term ownership of capital facilities via systematic acquisition, operation, maintenance, preservation, replacement, and disposition. Goals include optimizing life-cycle performance, minimizing life-cycle costs, and achieving maximum stakeholder benefit. Tools and techniques include design innovations, new construction technologies, materials improvements, geo-mapping, database management, value assessment, performance models, web-based communication, and cost accounting. Including asset management recognizes that civil engineers, during their careers, are likely to be involved with some aspect of capital facilities management.

14. **An understanding of business and public policy and administration fundamentals.**

    Commentary: The professional civil engineer typically functions within both the public and private sectors that requires at least an understanding of business, public policy, and public administration fundamentals.

    Important business fundamentals topics as typically applied in the private, government and non-profit sectors include legal forms of ownership, organizational structure and design, income statements, balance sheets, decision (engineering) economics, finance, marketing and sales, billable time, overhead, and profit.

Essential public policy and administration fundamentals include the political process, public policy, laws and regulations, funding mechanisms, public education and involvement, government-business interaction, and the public service responsibility of professionals.

15. **An understanding of the role of the leader and leadership principles and attitudes.**

    Commentary: Leading, in the private and public arena – which differs from and complements managing – requires broad motivation, direction, and communication knowledge and skills. Attitudes generally accepted as being conducive to leadership include commitment, confidence, curiosity, entrepreneurship, high expectations, honesty, integrity, judgment, persistence, positiveness, and sensitivity. Desirable behaviors of leaders, which can be taught and learned, include earning trust, trusting others, formulating and articulating vision, communication, rational thinking, openness, consistency, commitment to organizational values, and discretion with sensitive information.

APPENDIX II—TYPICAL BREAKDOWN OF COURSES AND OBJECTIVES SERVED

Math and Science (9 courses – 32 hrs)

Calculus 1	1, 11
Calculus 2	1, 11
Calculus 3	1, 11
Differential Equations	1
Statistics and Probability	1
Chemistry 1 (Lab)	1, 7
Science Elective	1
Physics 1 (Lab)	1, 5, 71

Engineering Science (5 courses – 15 hrs)

Statics	1, 5
Dynamics	1, 5
Mechanics of Materials	1, 2, 3, 5
Thermodynamics	1, 3, 5
Fluid Mechanics	1, 3, 5

Engineering Fundamentals (4 courses – 10 hrs)

Computer Applications in Engineering	1, 5, 7, 11
Fundamentals of Engineering Design	2, 3, 4, 6, 7, 15
Engineering Design	2, 3, 4, 6, 7, 8, 9, 10, 13, 15
Surveying	1, 4, 5, 6, 11

Engineering (12 courses – 39 hrs)

Hydraulic Engineering (Lab)	1, 2, 3, 5, 7, 11
Soil Mechanics (Lab)	1, 2, 3, 5, 7, 11
Structural Analysis	1, 3, 5, 7, 11
Steel / Concrete Design	1, 3, 5, 7, 11
Water Resources Engineering	1, 3, 5, 8, 10, 11
Water/Wastewater Design (Lab)	1, 2, 3, 5, 7, 11
Technical Elective	1, 3, 5
Civil Engineering Elective (3)	1, 2, 3, 5, 14
Senior Design 1	1, 2, 3, 4, 8, 15
Senior Design 2	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15

Professional (4 courses – 12 hrs)

Engineering and Public Policy	6
Professional, Ethical and Legal Issues in Engineering	6, 9, 10, 15
Managerial Economics	5, 6, 10, 14
Engineering Project Management	4, 13, 14

Humanities and Social Science (6 courses – 18 hrs)

English	7
History of American Engineering	6, 8, 10
History	
Technical Communications	2
English	7
Literature	10
	6, 8, 10

APPENDIX III— CURRICULUM DESIGN PARTNER INSTITUTIONS

The academic institutions represented on the Curriculum Committee are as follows:

- Bucknell University
- California State University—Los Angeles
- Case Western Reserve University
- Colorado State University
- Iowa State University
- Northern Arizona University
- Norwich University
- Pennsylvania State University
- Rose-Hulman Institute of Technology
- United States Military Academy
- University of Florida
- University of Illinois at Urbana-Champaign
- University of Louisville
- University of Nebraska
- University of Oklahoma
- University of Texas at Austin
- University of Texas at Tyler
- Virginia Military Institute
- Wentworth Institute of Technology
- Western Michigan University