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The ASCE BOK, ABET Accreditation Criteria, and NCEES FE Exam - Are They Appropriately Aligned?

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Introduction

Professional licensure is widely recognized as being critically important to the civil engineering profession. This is illustrated by the Civil Engineering Body of Knowledge[1] (BOK) being defined as the "knowledge, skills, and attitudes required for entry into the practice of civil engineering at the professional level," which equates to the ability to attain professional licensure. The BOK is published and maintained by the American Society of Civil Engineers (ASCE), and the first step for future civil engineers to fulfill the BOK is to achieve the outcomes related to the baccalaureate level of formal education. However, civil engineering programs are accredited based on criteria defined by ABET[2]. These criteria are influenced, but not defined, by the BOK. Finally, in addition to earning an ABET-accredited engineering degree, the first step towards professional licensure is to pass the Fundamentals of Engineering (FE) exam[3], which is administered by the National Council of Examiners for Engineering and Surveying (NCEES). The relationships between the BOK, ABET accreditation and the FE lead to several questions:

(1) Does the BOK adequately emphasize the knowledge, skills and attitudes required for successful preparation for the FE exam?
(2) Similarly, does current ABET accreditation criteria adequately address student preparation for the FE exam?
(3) If the BOK and/or ABET accreditation criteria are not aligned with or subsume the content of the FE exam, should they be changed or should the content of the FE exam be modified?

The purpose of this paper is to address these questions by examining and relating content of the civil engineering FE exam with (1) the provisions and outcomes in the current edition of the BOK, specifically the BOK outcomes associated with formal education at the baccalaureate level, and (2) current ABET general and civil engineering program accreditation criteria. NCEES data related to pass rates on the FE and performance on the various topic areas will be used to support recommendations for consideration in the next revisions of the BOK, accreditation criteria, and/or the FE exam.

Civil Engineering Body of Knowledge

As defined by ASCE[1,4] the BOK is "the necessary depth and breadth of knowledge, skills, and attitudes required of an individual entering the practice of civil engineering at the professional level in the 21st century." The second (current) edition of the BOK presents 24 foundational, technical and professional practice learning outcomes, including recommendations for fulfilling the outcomes through formal education, both at the baccalaureate and post-baccalaureate levels, and mentored pre-licensure experience. The current BOK outcome statements linked to the baccalaureate level are provided in Appendix A.

The BOK is intended to define the "knowledge, skills, and attitudes" required for the future and is not regulatory or intended to be prescriptive. Many of the outcomes defined in the BOK may be considered traditional for civil engineering. For example, BOK Outcome 14 at the baccalaureate level states graduates should be able to "analyze and solve well-defined engineering problems in at least four technical areas appropriate to civil engineering" without specifying the four areas. This is very similar to a long-standing provision within civil engineering program accreditation criteria. Correspondingly, there are other portions of the BOK that may be described as "aspirational" for the formal education and early career development of the future civil engineering professional. Accordingly, it is understood and expected that while some of the BOK outcomes directly translate into today's accreditation and licensure requirements, others do not.

ABET Accreditation

ABET accreditation[3] is the primary regulatory mechanism to assure engineering programs and their graduates meet minimum academic standards and expectations. While ABET accreditation criteria define a minimum academic standard, it still allows flexibility for programs to define their own objectives and outcomes, along with assessment processes. ABET mandates that there "must be a documented, systematically utilized, and effective process, involving program constituencies, for the periodic review of these program educational objectives that ensures they remain consistent with the institutional mission, the program's constituents' needs, and these criteria." Considering student outcomes and curricular content, the relevant ABET accreditation criteria are the General Criterion 3, Student Outcomes; General Criterion 5, Curriculum; and Program Criteria. These criteria are provided in Appendices B.1, B.2 and B.3, respectively. The General Criteria are applicable to all engineering disciplines whereas the Program Criteria are specific to each discipline.

Conceptually, since portions of the BOK are aspirational and ABET criteria are today's minimum standard for academic programs, one would expect ABET criteria to be equal to or less than the BOK recommended outcomes in terms of both level and breadth of achievement. As such, the Civil Engineering Program Criteria (CEPC) has been revised based upon both the first and second (current) editions of the BOK[5,6]. The relationship between the BOK outcomes and ABET accreditation criteria is presented in Appendix H of the BOK Report[2] and most recently reported on by Estes et al[5].

Note that ABET[2] has proposed a variety of changes to the General Criteria, with perhaps the most significant changes being to Criterion 3 Student Outcomes. While the current ABET criteria are considered in this paper, the proposed new Criterion 3 is provided in Appendix B.4 for reference. The proposed changes to Criterion 5 Curriculum are more editorial than substantive and, therefore, not included.

Fundamentals of Engineering (FE) Exam

The FE exam is the first of two tests required for professional licensure. The FE is intended to be taken by engineering students who are nearing completion of their degree or who have recently graduated. The FE exam is well defined and rather prescriptive in its content. The current FE exam is computer-based (versus pencil and paper) and includes 110 multiple-choice questions distributed into defined topic areas based on the discipline. For civil engineering, the

FE exam includes 18 different topical areas.[7] A complete breakdown of topic areas, number of questions included for each topic area, and the specific subjects within each area of the civil engineering FE exam is provided in Table 1.

Table 1. Content of the Civil Engineering FE Exam[7]

Topic Area	Number of Questions	Subjects within Area
Mathematics	7 – 11	Analytic geometry; calculus; roots of equations; vector analysis
Probability and Statistics	4 – 6	Measures of central tendencies and dispersions (e.g., mean, mode, standard deviation); estimation for a single mean (e.g., point, confidence intervals); regression and curve fitting; expected value, weighted average, in decision making
Computational Tools	4 – 6	Spreadsheet computations; structured programming (e.g., if-then, loops, macros)
Ethics and Professional Practice	4 – 6	Codes of ethics, professional and technical societies; professional liability; licensure; sustainability and sustainable design; professional skills (e.g., public policy, management, and business); contracts and contract law
Engineering Economics	4 – 6	Discounted cash flow; cost (e.g., incremental, average, sunk, estimating); analyses (e.g., breakeven, benefit-cost, life cycle); uncertainty (e.g., expected value and risk)
Statics	7 – 11	Resultants of force systems; equivalent force systems; equilibrium of rigid bodies; frames and trusses; centroid of area; area moments of inertia; static friction
Dynamics	4 – 6	Kinematics (e.g., particles and rigid bodies); mass moments of inertia; force acceleration, e.g., particles and rigid bodies; impulse momentum, e.g., particles and rigid bodies; work, energy, and power, e.g., particles and rigid bodies
Mechanics of Materials	7 – 11	Shear and moment diagrams; stresses and strains (e.g., axial, torsion, bending, shear, thermal); deformations (e.g., axial, torsion, bending, thermal); combined stresses; principal stresses; Mohr's circle; column analysis (e.g., buckling, boundary conditions); composite sections; elastic and plastic deformations; stress-strain diagrams
Materials	4 – 6	Mix design (e.g., concrete and asphalt); test methods and specifications (e.g., steel, concrete, aggregates, asphalt, wood); physical and mechanical properties of concrete, ferrous and nonferrous metals, masonry, wood, engineered materials (e.g., FRP, laminated lumber, wood/plastic composites) and asphalt
Fluid Mechanics	4 – 6	Flow measurement; fluid properties; fluid statics; energy, impulse, and momentum equations

Table 1. (continued)

Hydraulics and Hydrologic Systems	8 – 12	Basic hydrology, (e.g., infiltration, rainfall, runoff, detention, flood flows, watersheds); basic hydraulics (e.g., Manning equation, Bernoulli theorem, open-channel flow, pipe flow); pumping systems, water and wastewater; water distribution systems; reservoirs (e.g., dams, routing, spillways); groundwater (e.g., flow, wells, drawdown); storm sewer collection systems
Structural Analysis	6 – 9	Analysis of forces in statically determinant beams, trusses, and frames; deflection of statically determinant beams, trusses, and frames; structural determinacy and stability analysis of beams, trusses, and frames; loads and load paths (e.g., dead, live, lateral, influence lines and moving loads, tributary areas); elementary statically indeterminate structures
Structural Design	6 – 9	Design of steel components (e.g., codes and design philosophies, beams, columns, beam-columns, tension members, connections); design of reinforced concrete components (e.g., codes and design philosophies, beams, slabs, columns, walls, footings)
Geotechnical Engineering	9 – 14	Geology; index properties and soil classifications; phase relations, air-water-solid; laboratory and field tests; effective stress, buoyancy; stability of retaining walls (e.g., active pressure/passive pressure); shear strength; bearing capacity, cohesive and noncohesive; foundation types (e.g., spread footings, deep foundations, wall footings, mats); consolidation and differential settlement; seepage/flow nets; slope stability (e.g., fills, embankments, cuts, dams); soil stabilization (e.g., chemical additives, geosynthetics); drainage systems; erosion control
Transportation Engineering	8 – 12	Geometric design of streets and highways; geometric design of intersections; pavement system design (e.g., thickness, subgrade, drainage, rehabilitation); traffic safety; traffic capacity; traffic flow theory; traffic control devices; transportation planning (e.g., travel forecast modeling)
Environmental Engineering	6 – 9	Water quality, ground and surface; basic tests (e.g., water, wastewater, air); environmental regulations; water supply and treatment; wastewater collection and treatment
Construction	4 – 6	Construction documents; procurement methods (e.g., competitive bid, qualifications-based); project delivery methods (e.g., design-bid-build, design build, construction management, multiple prime); construction operations and methods (e.g., lifting, rigging, dewatering and pumping, equipment production, productivity analysis and improvement, temporary erosion control); project scheduling (e.g., CPM, allocation of resources); project management (e.g., owner/contractor/client relations); construction safety; construction estimating
Surveying	4 – 6	Angles, distances, trigonometry; area computations; earthwork and volume computations; closure; coordinate systems (e.g., state plane, latitude/longitude); leveling (e.g., differential, elevations, grades)

It would be inappropriate to use percent correct for each topical area to evaluate how exam takers perform on the various sections because each exam taker is given a different set of questions within each topic area and the difficulty of each set of questions may differ. Therefore, a statistical method[8] is used to create comparable performance indices for each topic area using a 0 to 15 scale. NCEES uses an "ABET Comparator Group," which is defined as those exam takers with similar background taking the same exam (e.g., examinees within 12 months of graduation date majoring in civil engineering and taking the civil engineering FE exam). Table 2 lists the topic areas, number of questions, and performance indices for each topical area for January/February and April/May exam period. Some of the lowest performance indices are in the traditional areas of civil engineering (hydraulics and hydrologic systems, structural analysis, structural design, geotechnical engineering, transportation engineering, environmental engineering, and surveying). Most of these also have lower variability in performance, indicating exam takers not only do poorer in these areas, but their performance is also consistently poor across all examinees.

Table 2. Topics Included and Performance in the Civil Engineering FE Exam*

Civil Engineering FE Exam Topics	Number of Exam Questions	ABET Comparator Average Performance Index	ABET Comparator Standard Deviation	ABET Competitor Coefficient of Variation
Mathematics	7	9.9	2.9	29.3%
Probability and Statistics	4	10.3	3.4	33.0%
Computational Tools	4	10.2	3.6	35.3%
Ethics and Professional Practice	4	10.9	3.7	33.9%
Engineering Economics	4	10.3	3.7	35.9%
Statics	7	9.7	2.7	27.8%
Dynamics	4	10.1	3.3	32.7%
Mechanics of Materials	7	9.2	2.2	23.9%
Materials	4	9.4	3.1	33.0%
Fluid Mechanics	4	10.5	3.6	34.3%
Hydraulics and Hydrologic Systems	8	9.1	2.1	23.1%
Structural Analysis	6	9.1	2.5	27.5%
Structural Design	6	8.9	2.5	28.1%
Geotechnical Engineering	9	9.1	2.0	22.0%
Transportation Engineering	8	9.1	2.3	25.3%
Environmental Engineering	6	9.3	2.7	29.0%
Construction	4	9.9	3.7	37.4%
Surveying	4	8.7	3.7	42.5%

*Data provided by NCEES for the January/February and April/May 2015 testing periods

To better understand the relative values of the performance indices and to provide a base of comparisons, Table 3 provides the performance indices for some of the basic topic areas that are included in the FE exams of the other large engineering disciplines. It is important to note that direct comparisons across topic areas would be inappropriate as specific subjects within each topic area differ by discipline. Nonetheless, the data in Table 3 indicates that test-takers' performance on the civil engineering FE exam is quite similar to the performance on other discipline exams in these common topic areas. Consequently, based on the FE performance data, it is reasonable to conclude civil engineering students are consistently performing more poorly on the traditional civil discipline specific subject matter than on engineering support subjects such as mathematics, computational tools, statistics, ethics, and engineering economics.

General Observations on Alignment

Is it reasonable to assume the BOK outcomes, ABET accreditation criteria, and FE exam content are appropriately aligned and supportive of the profession?

Full alignment between the BOK outcomes, ABET accreditation criteria, and the content of the FE may not be possible or practical since each is controlled by a different organization – ASCE, ABET and NCEES, respectively. However, it may be reasonable to assume some level of coordination and alignment because of common constituency groups shared by these three organizations. In fact, ASCE is the lead society for the ABET Civil Engineering Program Criteria (CEPC) and, as noted previously, the CEPC has been revised based upon both the first and second (current) editions of the BOK[5,6]. Therefore, there is considerable alignment between the BOK outcomes and ABET accreditation criteria. Estes et al.[5] provided a full analysis of the difference or gap between the current ABET Civil Engineering Criteria (general criteria plus program criteria) and the BOK outcomes.

As an aside, it is interesting to note that one topic where the ABET criteria might go beyond the expectations of the BOK outcomes is an explicit reference to professional licensure. However, since (1) the BOK defines the knowledge, skills and attitudes expected of an individual "entering the practice of civil engineering at the professional level" (to be a licensed professional engineer) and (2) pre-licensure education and experience are central themes of the BOK, the fact that licensure is not explicitly included in any of the 24 outcomes is perhaps not overly surprising. Nevertheless, awareness of the importance of licensure and, specifically, knowledge of the licensure process, content and expectations for passing the FE and PE exams, and the expectations and requirements for pre-licensure experience should be considered for explicit inclusion in the next edition of the BOK.

Since no formal connection exists between (1) ASCE's BOK or ABET's criteria and (2) NCEES's FE exam, one might speculate that academic programs may not be adequately preparing their graduates to be successful on the FE exam. Any potential misalignment might be evidenced in lower-than-expected performance on the FE. Table 4 provides the pass rate on the FE for first-time test takers. At 70% the civil engineering pass rate has the second lowest pass rate of the seven different FE exams. The civil engineering FE exam was taken by 4874 of the 12,835 (38%) first-time test takers, the most of the seven exams. In comparison, the mechanical engineering FE exam had second most number of takers with 3547 (28%) and the highest pass rate at 82%.

Table 3. Performance Indices for Basic Topic Areas Across Discipline FE Exams

FE Exam	FE Exam Topic Area Average Performance Index (Standard Deviation)								
	Mathematics	Probability and Statistics	Computational Tools	Ethics and Professional Practice	Engineering Economics	Statics	Dynamics	Mechanics of Materials	Fluid Mechanics
Chemical Engineering	10.7 (3.1)	10.7 (3.5)	10.6 (3.4)	11.1 (5.4)	NA	NA	NA	NA	9.9 (2.3)
Civil Engineering	9.9 (2.9)	10.3 (3.4)	10.2 (3.6)	10.9 (3.7)	10.3 (3.7)	9.7 (2.7)	10.1 (3.3)	9.2 (2.2)	10.5 (3.6)
Electrical and Computer Engineering	10.0 (2.5)	10.1 (3.4)	NA	11.8 (4.0)	9.5 (4.2)	NA	NA	NA	NA
Environmental Engineering	9.9 (3.4)	10.4 (3.8)	NA	10.7 (3.2)	NA	NA	NA	NA	9.4 (1.8)
Industrial Engineering	9.7 (2.4)	9.4 (1.9)	NA	9.9 (3.7)	9.1 (1.8)	NA	NA	NA	NA
Mechanical Engineering	10.6 (2.9)	10.0 (3.2)	11.1 (4.1)	11.6 (3.9)	10.7 (4.0)	9.8 (2.4)	9.7 (2.1)	9.6 (2.2)	9.9 (2.2)

*Data provided by NCEES for the January/February and April/May 2015 testing periods

Table 4. Pass Rates for FE Exams*

FE Exam	Number of Exam Takers	Pass Rate
Chemical Engineering	853	77%
Civil Engineering	4,874	70%
Electrical and Computer Engineering	1,217	75%
Environmental Engineering	657	75%
Industrial Engineering	248	64%
Mechanical Engineering	3,547	82%
Other Engineering Disciplines	1,439	81%

*Data provided by NCEES for the January/February and April/May 2015 testing periods

Comparison of the BOK, ABET Accreditation and FE Exam

How well aligned are the published BOK outcomes, ABET accreditation criteria, and the content of the FE exam?

Table 5 provides a side-by-side comparison of the topic areas included in the FE exam with relevant ABET accreditation criteria and BOK outcomes, specifically those associated with the bachelors degree. A qualitative review of Tables 1 and 5 reveals many topic areas of the FE exam have directly supporting accreditation criteria and BOK outcomes; mathematics, probability and statistics, and ethics and professional practice are FE exam areas that appear to have a strong alignment with ABET accreditation criteria and BOK outcomes. Other FE exam topic areas have only moderately related accreditation criterion and BOK outcomes. Computational tools, for example, on the FE exam are focused on structured programming and spreadsheet calculations. ABET and the BOK approach computational tools in a more general manner and as part of a broader set of modern tools and techniques needed for professional practice, and therefore have a moderate rather than strong alignment with ABET accreditation and BOK outcomes.

Engineering economics, statics, dynamics, mechanics of materials, materials, and fluid mechanics are FE topic areas that are within a traditional civil engineering curriculum. ABET accreditation criteria, though, do not prescribe specific topics, allowing these to count as part of the required “one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student’s field of study.” Statics, dynamics, mechanics of materials, and fluid mechanics are expected to be included in all or most civil engineering curricula owing to these topics serving as prerequisites to a wide variety of civil engineering topics and courses. Therefore, these topics appear to have modest alignment with ABET accreditation criteria, relying heavily on tradition. Engineering economics and materials, however, may or may not be part of all or most civil engineering programs through tradition and follow-on courses. Accordingly, engineering economics and materials may have weak alignment with ABET accreditation criteria.

Table 5. Comparison of FE Topic Areas with EAC Criteria and BOK Outcomes

<table>
<tr><th>FE Exam
Topic Area</th><th>ABET Criteria</th><th>BOK Outcomes</th></tr>
<tr><td>Mathematics</td><td>3(a): an ability to apply knowledge of mathematics, science, and engineering
5(a): one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline
CEPC: apply knowledge of mathematics through differential equations</td><td>1: Solve problems in mathematics through differential equations and apply this knowledge to the solution of engineering problems</td></tr>
<tr><td>Probability and Statistics</td><td>CEPC: apply probability and statistics to address uncertainty</td><td>12: Apply the principles of probability and statistics to solve problems containing uncertainties</td></tr>
<tr><td>Computational Tools</td><td>3(k): an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice</td><td>8: Develop problem statements and solve well-defined fundamental civil engineering problems by applying appropriate techniques and tools</td></tr>
<tr><td>Ethics and Professional Practice</td><td>3(f): an understanding of professional and ethical responsibility
CEPC: analyze issues in professional ethics
CEPC: include principles of sustainability in design
CEPC: explain basic concepts in project management, business, public policy, and leadership</td><td>24: Analyze a situation involving multiple conflicting professional and ethical interests to determine an appropriate course of action.
10: Apply the principles of sustainability to the design of traditional and emergent engineering systems
17: Discuss and explain key concepts and processes involved in public policy
18: Explain key concepts and processes used in business and public administration</td></tr>
<tr><td>Engineering Economics</td><td rowspan="6">5(b): one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study.</td><td>No related outcomes</td></tr>
<tr><td>Statics</td><td rowspan="3">6: Analyze and solve problems in solid and fluid mechanics</td></tr>
<tr><td>Dynamics</td></tr>
<tr><td>Mechanics of Materials</td></tr>
<tr><td>Materials</td><td>5: Use knowledge of materials science to solve problems appropriate to civil engineering</td></tr>
<tr><td>Fluid Mechanics</td><td>6: Analyze and solve problems in solid and fluid mechanics</td></tr>
</table>

Table 5. (continued)

<table>
<tr><td>Hydraulics and Hydrologic Systems</td><td rowspan="8">3(c): an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
5(b): one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study.
5: Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.
CEPC: analyze and solve problems in at least four technical areas appropriate to civil engineering
CEPC: design a system, component, or process in at least two civil engineering contexts</td><td rowspan="8">9: 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
14: Analyze and solve well-defined engineering problems in at least four technical areas appropriate to civil engineering</td></tr>
<tr><td>Structural Analysis</td></tr>
<tr><td>Structural Design</td></tr>
<tr><td>Geotechnical Engineering</td></tr>
<tr><td>Transportation Engineering</td></tr>
<tr><td>Environmental Engineering</td></tr>
<tr><td>Construction</td></tr>
<tr><td>Surveying</td></tr>
</table>

The BOK's Outcome 6 states that graduates must be able to "analyze and solve problems in solid and fluid mechanics." This specifically relates to the FE exam topic areas of statics, dynamics, mechanics of materials, and fluid mechanics, hence alignment between the FE and BOK may be assumed strong in these areas. Engineering economics is not explicitly included in any BOK outcome, so it would be considered to have weak alignment with the BOK. While the topic area of materials is explicitly included in a stand-alone BOK outcome, it may be interpreted to be more fundamentally orientated towards material science than mix design, macro-material properties and test methods. Materials may even be considered a separate technical area within civil engineering (e.g., ASCE publishes the *Journal of Materials in Civil Engineering*). Regardless, materials may be considered to have moderate alignment between the FE exam and the BOK.

Approximately half of the FE exam includes questions in the following traditional technical areas of civil engineering: hydraulics and hydrologic systems, structural analysis, structural design, geotechnical engineering, transportation engineering, environmental engineering, and surveying. The ABET CEPC, which is consistent with the BOK, requires graduates to be able to "analyze and solve problems in at least four technical areas appropriate to civil engineering."

The current accreditation criteria and BOK specify that civil engineers should have a breadth of knowledge in civil engineering across at least four areas appropriate to civil engineering, but it does not prescribe the four areas. By not specifying the four areas, ABET and the BOK promote the idea of programs working with their constituency groups to include appropriate and relevant engineering content, within defined bounds, and set appropriate learning outcomes. The FE exam, however, requires all civil engineering FE test takers to answer questions in all eight areas (seven areas if structural analysis and structural design are considered one area) that are prescribed. This results in what would be considered a weak alignment between the FE exam and both ABET criteria and the BOK.

A final area of potential discrepancy is the area of design, which is not specific to any FE exam topic area but is explicitly stated in multiple ABET criterion and the BOK. The BOK's Outcome 9 calls for graduates to "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." The ABET General Criterion 3 requires "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." ABET General Criterion 5 also requires that "students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints." The ABET Civil Engineering Program Criteria requires the curriculum to prepare graduates to "design a system, component, or process in at least two civil engineering contexts" and to "include principles of sustainability in design." In comparison, the FE exam explicitly includes design in three topic areas: (1) materials, including concrete and asphalt mix design; (2) structural design, including steel and concrete structures; and (3) transportation engineering, including geometric design of streets and highways, geometric design of intersections, and pavement system design (e.g., thickness, subgrade, drainage, rehabilitation). Arguably, mix design as included in the materials section of the FE exam may not meet the design level expected in the BOK or ABET, but certainly the topics included in structural design and transportation engineering would be expected to be true design problems. The FE may also implicitly include design in other areas as well, such as in hydraulics and hydrologic systems, environmental engineering, and geotechnical engineering. Regardless, the BOK and ABET do not prescribe areas of design experience or preparation, but the FE exam requires design in multiple areas, including structural steel design, reinforced concrete design, geometric design of roads, highways, and intersections, and pavement design. This results in what is considered as a weak alignment between the FE exam and both ABET criteria and the BOK in terms of design expectations.

Assessment of Comparisons

Are the identified weak alignments between the BOK outcomes, ABET accreditation criteria, and the FE exam resulting in a lower-than-expected test-taker performance?

A summary of the qualitative assessment of the alignment between the FE exam and both ABET accreditation criteria and the BOK is provided in Tables 6A and 6B. Also included in Tables 6A and 6B are the ABET comparator average performance indices from Table 2; an asterisk indicates the performance index is in the lower half of all indices for the Civil Engineering FE

Table 6A. Summary of Qualitative Assessment of Alignment
(Ordered by topic areas corresponding to Tables 1, 2 and 5)

FE Exam Topic Area	Alignment with ABET	Alignment with BOK	ABET Comparator Average Performance Index
Mathematics	Strong	Strong	9.9
Probability and Statistics	Strong	Strong	10.3
Computational Tools	Moderate	Moderate	10.2
Ethics and Professional Practice	Strong	Strong	10.9
Engineering Economics	Weak	Weak	10.3
Statics	Moderate	Strong	9.7
Dynamics	Moderate	Strong	10.1
Mechanics of Materials	Moderate	Strong	9.2*
Materials	Weak	Moderate	9.4*
Fluid Mechanics	Moderate	Strong	10.5
Hydraulics and Hydrologic Systems	Weak	Weak	9.1*
Structural Analysis	Weak	Weak	9.1*
Structural Design	Weak	Weak	8.9*
Geotechnical Engineering	Weak	Weak	9.1*
Transportation Engineering	Weak	Weak	9.1*
Environmental Engineering	Weak	Weak	9.3*
Construction	Weak	Weak	9.9
Surveying	Weak	Weak	8.7*

*Lowest 9 of 18 Performance Indices

exam (January/February and April/May 2015 testing periods). Table 6A is ordered by FE exam topic areas for direct comparisons with Tables 1 and 2. Table 6B is ordered by the ABET comparator average performance index from low to high. Ten of the 18 topic areas were identified as having a weak alignment between ABET accreditation criteria and the FE exam content; 8 of 18 topic areas were determined to have either strong or moderate alignment. Similarly, 9 of 18 topic areas were determined as having weak alignment between the FE exam and the BOK with remaining 9 topic areas classified as having either a moderate or strong alignment. The topic area of materials was rated as having weak alignment between the FE exam content and ABET criteria yet moderate alignment with the BOK.

Except for engineering economics, all FE topic area identified as having weak alignment with ABET accreditation criteria or the BOK outcomes had performance indices in the lower half of all scores. Of the 8 FE exam topic areas rated with strong or moderate alignment with ABET accreditation criteria, only mechanics of materials had a performance index in the lower half of all scores. The materials topic area had the highest performance index within the lower half and was rated as weak with respect to ABET criteria and as moderate with the BOK.

Table 6B. Summary of Qualitative Assessment of Alignment
(Ordered by ABET Comparator Average Performance Index from low to high)

FE Exam Topic Area	Alignment with ABET	Alignment with BOK	ABET Comparator Average Performance Index
Surveying	Weak	Weak	8.7*
Structural Design	Weak	Weak	8.9*
Transportation Engineering	Weak	Weak	9.1*
Structural Analysis	Weak	Weak	9.1*
Hydraulics and Hydrologic Systems	Weak	Weak	9.1*
Geotechnical Engineering	Weak	Weak	9.1*
Mechanics of Materials	Moderate	Strong	9.2*
Environmental Engineering	Weak	Weak	9.3*
Materials	Weak	Moderate	9.4*
Mathematics	Strong	Strong	9.9
Statics	Moderate	Strong	9.7
Construction	Weak	Weak	9.9
Dynamics	Moderate	Strong	10.1
Computational Tools	Moderate	Moderate	10.2
Probability and Statistics	Strong	Strong	10.3
Engineering Economics	Weak	Weak	10.3
Fluid Mechanics	Moderate	Strong	10.5
Ethics and Professional Practice	Strong	Strong	10.9

*Lowest 9 of 18 Performance Indices

Evaluation and Implications

Are the identified weak alignments between the BOK outcomes, ABET accreditation criteria, and the FE exam valid and do they contribute to a lower-than-expected pass rate?

As noted in the previous section and as presented in Table 6A, there is a strong correlation between the results of qualitative comparison and the performance index for the various FE exam topic areas. For example, considering ABET accreditation criteria, 8 of the 10 topic areas identified as having a weak alignment had performance indices in the lower half of all topic areas. These topic areas include surveying, structural analysis, structural design, transportation engineering, hydraulics and hydrologic systems, geotechnical engineering, environmental engineering, and materials. Similarly, 7 of the 8 topic areas noted as having strong or moderate alignment corresponded with the higher half of the performance indices, and included mathematics, statics, dynamics, computational tools, probability and statistics, fluid mechanics, and ethics and professional practice. The strong correlation indicates that the comparisons and the weak (8 of 10) and moderate/strong ratings (7 of 8) for alignment are, for the most part, valid and accurate.

The three exceptions to the observed correlation are mechanics of materials, construction, and engineering economics. Mechanics of materials has a lower performance index yet was rated as having a moderate alignment between ABET accreditation criteria and the FE exam, and a strong alignment between the BOK and the FE. Construction and engineering economics both had higher performance indices but were rated as having a weak alignment with the FE exam for both ABET and the BOK. To fully understand and explain reasons for these three inconsistences would require a more in-depth analysis. Possible explanation may be related to the specific evolution of civil engineering curricula as dictated by both accreditation criteria and constituency input.

All in all, with 15 of 18 topic areas showing a strong correlation between the rated level of alignment (weak, moderate/strong) and test-taker performance (performance index), a reasonable conclusion is that a misalignment exists between what is expected of academic programs for their graduates, whether in terms of aspirational expectations expressed by the BOK or the minimum expectations as defined by ABET, and what is expected of civil engineering graduates through the FE exam. Furthermore, based on the qualitative comparisons and assessment of alignment with results of the FE exam (Tables 6A and 6B), there is good reason to conclude that the BOK, ABET accreditation criteria, and the FE exam are not properly or adequately aligned, and that this misalignment results in a lower-than-expected or desired pass rates on the FE exam.

The relationship between lower performance indices and the breadth of civil engineering technical areas is indisputable; the only civil engineering technical topic area not in the lower half of performance indices is construction. ABET accreditation and the BOK both promote having programs work with their constituency groups to include program content within defined bounds (e.g., "at least four technical areas appropriate to civil engineering"). ABET[2] states that the "criteria are intended to assure quality and to foster the systematic pursuit of improvement in the quality of engineering education that satisfies the needs of constituencies in a dynamic and competitive environment." The FE exam, on the other hand, mandates examinees answer questions in eight separate technical areas of civil engineering (seven areas if structural analysis and structural design are considered one area). Therefore, not only does the FE exam prescribe the areas, but also the number of areas is nominally double the minimum number of areas required for accreditation. To support this observed misalignment and its effect on test-taker performance, recall from Table 3 that the performance of civil engineering FE exam test takers appears to be very comparable to the performance of test takers of the other discipline exams on common topic areas. Therefore, it is appropriate to conclude that the lower pass rate on the civil engineering FE exam is related to the lower performance of examinees on the breadth of civil engineering technical topic areas.

Compounding this is how civil engineering design is included in the FE exam versus how it is handled in both the BOK and ABET accreditation criteria. BOK Outcome 9 expects graduates to "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." The ABET Civil Engineering Program Criteria similarly requires the curriculum to prepare graduates to "design a system, component, or process in at least two civil engineering contexts" and to "include principles of sustainability in design." The FE exam, on the other hand, explicitly includes design in materials, structures, and transportation. An obvious mismatch exists as the BOK and ABET do not prescribe specific areas of design experience or preparation while the FE exam requires design in multiple specific areas.

Overall, civil engineering FE exam takers are put into a disadvantaged position because of the identified weak alignments between what is expected of academic programs for their graduates and what is expected of these same graduates on the FE exam. The fact is no exam taker – or at least very few – would be adequately prepared and have confidence in answering questions in the full breath of civil engineering technical topic areas, including the breadth of specific design topics, on the FE exam. It follows that exam takers may likely become concerned they are inadequately prepared or that their program of study did not fully prepare them to be successful on the FE exam. This, in turn can potentially lead to test anxiety and a reduced level of performance in all knowledge and skill areas, both those considered to be an area of strength of an exam taker and those to be considered areas of weakness.[9] Therefore, since civil engineering programs are not required or expected to cover the full breadth of civil engineering technical areas or the specific areas of design that are included in the FE exam, exam takers may advertently be put in a position that does not allow them to fully, adequately, or accurately demonstrate their engineering knowledge and skills.

Recommendations

Should ASCE's BOK and ABET's criteria prescribe specific areas of civil engineering and design to be included in an undergraduate civil engineering program and then work with NCEES to limit the FE exam to these same areas? Should the format of the civil engineering FE exam be modified to allow the flexibility reflected in current ABET accreditation criteria, the BOK, and the diversity of today's civil engineering professional practice? Or should nothing be done, accepting the current status as appropriate for the profession?

First off, it must be recognized that with the many constraints and requirements placed on today's civil engineering programs – including regional accreditation requirements, institutional general education requirements, as well as ABET accreditation requirements – it would be impossible to expect all programs to cover the full breadth of civil engineering topic areas currently included in the FE exam, including the specific areas of civil engineering design covered in the FE exam. Furthermore, to do so would be highly prescriptive and would severely limit the flexibility that has long been afforded and expected of civil engineering programs by ABET to work with their constituency groups in defining their program objectives, outcomes and curriculum. Finally, prescribing the full breadth would be, in the very least, fiscally challenging to most civil engineering programs.

While the BOK, ABET accreditation criteria and the FE exam are administered by different organizations, a reasonable level of alignment should be achievable because of common constituency groups shared by these three organizations. Based on this assumption and the evaluations presented herein, the following recommendations are made regarding the ASCE BOK, ABET accreditation, and the FE exam:

Recommendations for the ASCE BOK. The BOK defines the knowledge, skills and attitudes expected of an individual "entering the practice of civil engineering at the professional level" (to be a licensed professional engineer). However, licensure is not specifically included within any of the BOK outcomes. It is recommended that an awareness of the importance of professional licensure and, specifically, knowledge of the licensure process, content and expectations for passing the FE and PE exams, and the expectations and requirements for pre-licensure experience be explicitly included in the BOK, either as a separate outcome or as part of a revised existing outcome. Owing to the importance of licensure to the profession, the preferable option is to include it as a separate, stand-alone outcome.

Recommendations for ABET accreditation criteria. It is interesting to note that licensure is not explicitly included in the general criteria and is explicitly included in only 2 of the 28 separate program criteria; civil engineering and construction engineering criteria both include the requirement for the curriculum prepare graduates to "explain the importance of professional licensure." While it is recognized that viewpoints regarding the importance of and need for professional licensure varies by discipline, it seems part of any engineering program should include providing students/graduates with a general understanding and awareness of professional licensure within engineering. It is recommended that professional licensure, in an appropriate manner applicable to all disciplines, be included in the general criteria. The preferable option would be to include it as a student outcome under General Criterion 3; alternatively it could be included as a curricular requirement within General Criterion 5.

Recommendations for the FE exam. The misalignment identified between what is expected of civil engineering programs for their graduates and what is expected of civil engineering graduates through the FE exam is significant and has the potential of negatively impacting test-taker performance on the exam. It is recommended that the FE exam change such that it is better aligned with current ABET accreditation criteria and the BOK. Specifically, one option would be to allow examinees to, either prior to or at test time, simply select four of the current civil engineering topic areas (hydraulics and hydrologic systems, structural analysis, structural design, geotechnical engineering, transportation engineering, environmental engineering, construction, and surveying) for which they wish to answer questions. Additional questions would need to be assigned and answered within the areas selected by the test taker so as to maintain a total of 110 questions. Design questions may be still included within the topic areas because test-takers should be able to demonstrate their abilities and knowledge of design within at least two of their selected topic areas. Allowing students to select their own areas of focus should be easily accomplished within the computer-based testing environment.

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Appendix A
Civil Engineering BOK Baccalaureate-Level Outcome Statements[1]

Outcome 1 – Solve problems in mathematics through differential equations and apply this knowledge to the solution of engineering problems

Outcome 2 – Solve problems in calculus-based physics, chemistry, and one additional area of natural science and apply this knowledge to the solution of engineering problems

Outcome 3 – Demonstrate the importance of the humanities in the professional practice of engineering

Outcome 4 – Demonstrate the incorporation of social sciences knowledge into the professional practice of engineering

Outcome 5 – Use knowledge of materials science to solve problems appropriate to civil engineering

Outcome 6 – Analyze and solve problems in solid and fluid mechanics

Outcome 7 – Analyze the results of experiments and evaluate the accuracy of the results within the known boundaries of the tests and materials in or across more than one of the technical areas of civil engineering

Outcome 8 – Develop problem statements and solve well-defined fundamental civil engineering problems by applying appropriate techniques and tools

Outcome 9 – 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

Outcome 10 – Apply the principles of sustainability to the design of traditional and emergent engineering systems

Outcome 11 – Drawing upon a broad education, explain the impact of historical and contemporary issues on the identification, formulation, and solution of engineering problems and explain the impact of engineering solutions on the economy, environment, political landscape, and society

Outcome 12 – Apply the principles of probability and statistics to solve problems containing uncertainties

Outcome 13 – Develop solutions to well-defined project management problems

Outcome 14 – Analyze and solve well-defined engineering problems in at least four technical areas appropriate to civil engineering

Outcome 15 – Define key aspects of advanced technical specialization appropriate to civil engineering

Outcome 16 – Organize and deliver effective verbal, written, virtual, and graphical communications

Outcome 17 – Discuss and explain key concepts and processes involved in public policy

Outcome 18 – Explain key concepts and processes used in business and public administration

Outcome 19 – Organize, formulate, and solve engineering problems within a global context

Outcome 20 – Apply leadership principles to direct the efforts of a small, homogeneous group

Outcome 21 – Function effectively as a member of a multidisciplinary team

Outcome 22 – Explain attitudes supportive of the professional practice of civil engineering

Outcome 23 – Demonstrate the ability for self-directed learning

Outcome 24 – Analyze a situation involving multiple conflicting professional and ethical interests to determine an appropriate course of action

Appendix B.1
General Criterion 3 – Student Outcomes[2]
The program must have documented student outcomes that prepare graduates to attain the program educational objectives.

Student outcomes are outcomes (a) through (k) plus any additional outcomes that may be articulated by the program.

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Appendix B.2
General Criterion 5 – Curriculum[2]

The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The faculty must ensure that the program curriculum devotes adequate attention and time to each component, consistent with the outcomes and objectives of the program and institution. The professional component must include:

(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline. Basic sciences are defined as biological, chemical, and physical sciences.

(b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. 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.

(c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.

One year is the lesser of 32 semester hours (or equivalent) or one-fourth of the total credits required for graduation.

Appendix B.3
Curriculum Criterion for Civil and Similarly Named Engineering Programs[2]
The curriculum must prepare graduates to apply knowledge of mathematics through differential equations, calculus-based physics, chemistry, and at least one additional area of basic science; apply probability and statistics to address uncertainty; analyze and solve problems in at least four technical areas appropriate to civil engineering; conduct experiments in at least two technical areas of civil engineering and analyze and interpret the resulting data; design a system, component, or process in at least two civil engineering contexts; include principles of sustainability in design; explain basic concepts in project management, business, public policy, and leadership; analyze issues in professional ethics; and explain the importance of professional licensure.

Appendix B.4
Proposed New Criterion 3 – Student Outcomes[2]
The program must have documented student outcomes. Attainment of these outcomes prepares graduates to enter the professional practice of engineering.

Student outcomes are outcomes (1) through (7) plus any additional outcomes that may be articulated by the program.

1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.
3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
4. An ability to communicate effectively with a range of audiences.
5. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.
7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.