

Raising the Bar for Civil Engineering: Implications of the International Engineering Alliance Graduate Attribute Profiles

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Background and Relevant Literature

The International Engineering Alliance (IEA) is a representative organization, composed of the signatories to a series of international agreements regarding engineering and engineering technology accreditation and professional licensure.¹ The three IEA agreements governing accreditation are the Washington Accord, for engineering programs; the Sydney Accord, for baccalaureate-level engineering technology programs; and the Dublin Accord, for associate-level engineering technician programs.² All three accords—also known as *mutual recognition agreements*—are non-governmental agreements among national-level accreditation organizations. Through these accords, participating organizations recognize the *substantial equivalency* of each other's accreditation processes and of their graduates' academic preparation to enter professional practice. Accreditation systems that are substantially equivalent have comparable—though not necessarily identical—standards, outcomes, and processes. On the basis of substantial equivalency, the accords recommend that graduates of programs accredited by any of the signatory organizations be recognized by all other signatories as having met the academic requirements for entry into professional practice.

The Washington, Sydney, and Dublin accords were established in 1989, 2001, and 2002, respectively. ABET was a founding member of the Washington accord but did not join the Sydney Accord until 2009 or the Dublin Accord until 2007.^{3,4,5} The accreditation organizations of 17 countries are current signatories to the Washington Accord, and six more hold provisional memberships.

In June 2001, recognizing the importance of using uniform standards as the basis for judging substantial equivalency, the IEA began a long-term process of defining mutually agreeable Graduate Attribute Profiles and Professional Competency Profiles for the three principal categories of practitioners—engineers, engineering technologists, and engineering technicians. The Graduate Attribute Profiles are three sets of assessable outcomes, each of which reflects a graduate's potential to acquire the competence necessary to practice within a given category. The Professional Competency Profiles define the elements of competency that a practitioner is expected to demonstrate at the time of attaining registration.* The IEA Graduate Attribute and Professional Competency Profiles are, by design, applicable to all engineering disciplines. The IEA adopted the first version of these profiles in June 2005, and the most recent update was published in June 2013.⁶ The current IEA Graduate Attribute and Professional Competency Profiles are based on extensive scholarly analysis and coordination.⁷

In the ABET accreditation system, the equivalent of the IEA Graduate Attribute Profiles is a series of *student outcomes* listed in each of the accreditation criteria established by ABET's four

* It is worth noting that, unlike the United States, many countries have institutionalized systems for registering technicians and technologists, as well as for registering or chartering professional engineers.

commissions.* Specifically, in all four sets of criteria, the required attributes of graduates are specified in Criterion 3 (Student Outcomes) and supplemented by certain provisions of Criterion 5 (Curriculum).

Criteria 3 and 5 of the ABET Engineering Accreditation Commission (EAC) Criteria for Accrediting Engineering Programs are currently undergoing a major revision.⁹ This process—the first substantial update to the EAC student outcomes since ABET adopted outcomes-based accreditation criteria in the late 1990s—was initiated in 2009 by the EAC Criteria Committee. In response to a variety of stakeholder inputs suggesting that the student outcomes needed to be revisited, the EAC convened a task force to gather additional input, review relevant literature, and prepare revised criteria. ABET’s recently published “Rationale for Revising Criteria 3 and 5” indicates that, as part of this process, the task force reviewed the IEA Graduate Attribute and Professional Competency Profiles.¹⁰

In July 2015, substantially revised Criteria 3 and 5 were approved by the EAC; and in October 2015, the EAC presented the proposed criteria to the Engineering Area Delegation of the ABET Board of Delegates for approval. The Engineering Area Delegation approved the proposed criteria on first reading, albeit with considerable discussion and some dissent. The proposed criteria are currently undergoing public review, with the public comment period ending on June 15, 2016. They will be considered for final approval by the EAC and the Engineering Area Delegation in July 2016 and October 2016, respectively.

Both the IEA Graduate Attribute Profiles and the proposed revisions to ABET EAC Criteria 3 and 5 are of significant consequence to the American Society of Civil Engineers (ASCE) “Raise the Bar” initiative.** The IEA Profiles constitute a rigorous, coherent, comprehensive set of descriptors for the knowledge and skills expected of engineering and engineering technology graduates in a global context. Thus, in addition to their role as the basis for compliance with mutual recognition agreements, these profiles also represent an authoritative framework for the *bodies of knowledge* for engineers, engineering technologists, and engineering technicians. As such, they constitute a potentially important source of input to the ongoing ASCE “Raise the Bar” initiative and its associated effort to articulate the Civil Engineering Body of Knowledge (CE BOK) and the Civil Engineering Technology Body of Knowledge (CET BOK). Although the CE BOK was formally articulated and published in 2004,¹² ASCE considers it a dynamic document that must be systematically reviewed and updated on a regular basis. Thus, a second edition of the CE BOK was published in 2008,¹³ and the process of formulating a third edition is scheduled to begin in 2016, with the establishment of a new BOK task committee. The current (second) edition of the CE BOK did not use the IEA Graduate Attribute Profiles as a source, because the profiles were not finalized until 2013. A first-edition BOK for Civil Engineering Technology is also currently in development.

* The accreditation mission of ABET is implemented by its four commissions—the Engineering Accreditation Commission (EAC), Engineering Technology Accreditation Commission (ETAC), Computing Accreditation Commission (CAC), and Applied Science Accreditation Commission (ASAC).⁸ Each commission establishes its own unique set of accreditation criteria; however, the criteria numbering scheme is harmonized across commissions.

**For further background information on the ASCE “Raise the Bar” initiative, see Reference 11.

The current CE BOK is articulated in terms of 24 outcomes, which collectively define the knowledge, skills, and attitudes required for entry into the professional practice of civil engineering. Each outcome has a specified minimum *level of achievement* associated with baccalaureate-level education, master's (or equivalent)-level education, and pre-licensure experience.¹³

The educational component of the CE BOK is operationalized through accreditation. In this process, the CE BOK outcomes, which are not in any way enforceable, are translated into appropriate accreditation criteria, which are enforceable through the ABET accreditation process.¹⁴ Thus, accreditation criteria provide the mechanism by which civil engineering curricula are brought into closer alignment with the CE BOK. Logically, this alignment *should* conform with the three categories of ABET criteria as follows:

- Non-discipline-specific CE BOK outcomes at the level of achievement specified for baccalaureate-level education should translate into provisions of the EAC General Criteria for Baccalaureate Level Programs.
- Non-discipline-specific CE BOK outcomes at the level of achievement specified for master's-level education should translate into provisions of the EAC General Criteria for Master's Level Programs.
- Civil engineering discipline-specific CE BOK outcomes should translate into provisions of the Civil Engineering Program Criteria.¹⁵

In practice, however, this translation of CE BOK outcomes to accreditation criteria has not been so simple or logical, in two successive iterations of the process.^{14,16} Because the Baccalaureate-Level and Master's-Level General Criteria must necessarily be applicable to all engineering disciplines and are subject to the approval of all associated ABET Member Societies,* significant changes to these criteria are quite rare; and when they do occur, such changes must be deemed acceptable by a majority of the Member Societies. Thus, ASCE generally exerts relatively little influence over these criteria. Conversely, ASCE can exert substantially greater influence over the Civil Engineering Program Criteria. Consequently, in operationalizing the CE BOK, ASCE has found it necessary to include some non-discipline-specific provisions in the Civil Engineering Program Criteria, simply because inclusion of these provisions in the General Criteria would have been politically infeasible. Several of these provisions—including requirements for knowledge of statistics, sustainability, project management, and business—are addressed in the IEA Graduate Attribute Profiles but not in the current EAC General Criteria.¹⁵

Given this situation, the ongoing change to EAC Criteria 3 and 5 represents a unique opportunity to bring the EAC Criteria for Accrediting Engineering Programs into a closer and more logical alignment with the CE BOK, through enhanced consistency with the IEA Graduate Attribute Profiles. A necessary prerequisite for enhanced consistency is a rigorous comparison of the IEA Graduate Attribute Profiles with the current and proposed EAC Criteria 3 and 5. To date, the authors know of no such comparison that has been published.

* ABET currently has 35 member societies, 27 of which have seats in the Engineering Area Delegation—the ABET governing body with approval authority over the EAC Criteria for Accrediting Engineering Programs.

Purpose and Scope

This paper seeks to address the following research question: *To what extent are the current and proposed versions of the ABET EAC Criteria for Accrediting Engineering Programs consistent with IEA Graduate Attribute Profiles?*

The purposes of this analysis are (1) to help inform ASCE's response to the proposed changes to EAC Criteria 3 and 5; and (2) to identify aspects of the IEA Graduate Attribute Profiles that are worthy of consideration for inclusion in the Civil Engineering Body of Knowledge (CE BOK), 3rd edition.

The scope of this paper is focused primarily on *engineering accreditation* and, thus, on the single IEA Graduate Attribute Profile for Washington Accord (i.e., engineering) programs. In this paper, accreditation of engineering technology and engineering technician programs is considered only insofar as the associated IEA Profiles provide useful distinctions between accreditation standards for the three categories of practitioners. The IEA Professional Competency Profiles are beyond the scope of this paper, as they apply to professionals at the time of registration.

Methodology

The authors address this research question through the following methodology:

- (1) Examine the content and structure of the IEA Graduate Attribute Profiles, with emphasis on the profile for Washington Accord programs.
- (2) Compare the IEA Graduate Attribute Profile for engineering with the current ABET EAC Criteria and the proposed revisions to these criteria, identifying any substantive discrepancies between them.
- (3) Make a qualitative judgment about the extent to which the IEA Profiles and the EAC Criteria should be brought into closer agreement.
- (4) Based on this judgment, recommend the response that ASCE should provide to ABET regarding the proposed changes to EAC Criteria 3 and 5.
- (5) Identify implications of this comparison for the ASCE "Raise the Bar" initiative and, more specifically, for the development of the CE BOK, 3rd edition.

The IEA Graduate Attribute Profiles

The IEA Graduate Attribute Profiles are provided as Appendix A of this paper. The IEA's comprehensive description of their purpose, limitations, and organization is provided in Reference 6.

Note that the Profiles are organized in terms of twelve *differentiating characteristics*—engineering knowledge, problem analysis, design/development of solutions, investigation, modern tool usage, the engineer and society, environment and sustainability, ethics, individual and team work, communication, project management and finance, and lifelong learning. Because these characteristics are logically distinct, they result in *individually assessable* graduate

attributes. The remaining three columns contain the Graduate Attribute Profiles for Washington Accord (i.e., engineering) graduates, identified as WA1-WA12; Sydney Accord (i.e., engineering technology) graduates, SA1-SA12; and Dublin Accord (i.e., engineering technician) graduates, DA1-DA12.

Note also that all individual elements of the Graduate Attribute Profiles refer to associated elements (designated, for example, WK1, SK4, DK7) in an accompanying **Knowledge Profile**, provided as Appendix B of this paper. The IEA Knowledge Profile describes the types and levels of knowledge required of engineering, engineering technology, and engineering technician graduates in eight different domains—natural science, mathematics, engineering fundamentals, engineering specialist knowledge, engineering design, engineering practice, engineering in society, and research literature. The Knowledge Profile effectively adds a third dimension to the two-dimensional Graduate Attribute Profiles, providing a rich description of the knowledge associated with each attribute, for all three categories of practitioners.

For example, Graduate Attribute WA1 specifies that engineers must “apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization...”, but tells us nothing about the nature of the required mathematical, scientific, and engineering knowledge. The Knowledge Profile resolves this ambiguity, specifying, for example, that the mathematics should include “statistics and formal aspects of computer and information science to support analysis and modeling” (WK2); that the natural sciences should be systematic and theory-based (WK1); and that much of the engineering specialist knowledge should be “at the forefront of the discipline” (WK4). Thus the Knowledge Profile adds considerable substance to attributes that might otherwise have been viewed as vague or overly broad.

The Graduate Attribute Profiles have been further enhanced by a similarly structured **Range of Problem Solving matrix**, provided as Appendix C of this paper. This matrix is organized in terms of the types of problems expected to be solved by practitioners in each category—*complex problems* for engineers, *broadly-defined problems* for engineering technologists, and *well-defined problems* for engineering technicians. The matrix defines complex, broadly-defined, and well-defined problems precisely and comprehensively, in terms of the depth of knowledge required, range of conflicting requirements, depth of analysis required, familiarity of issues, extent of applicable codes, stakeholder involvement, interdependence, consequences, and judgment required. These three types of problems are referenced throughout the Graduate Attribute Profiles, thus providing the basis for powerful, unambiguous differentiation between the required attributes of engineers, technologists, and technicians.

Overview of the Comparison

Table 1 (below) provides a direct side-by-side comparison of the individual elements of the IEA Graduate Attributes Profile for Washington Accord programs with corresponding relevant provisions of the current and proposed EAC Criteria for Engineering Programs. Columns 1 and 2 of this table present the IEA’s twelve differentiating characteristics and the associated graduate attributes for engineering programs. Column 3 shows the corresponding provisions of the *current* EAC Criterion 3—eleven outcomes designed (a)-(k). Column 4 shows the *proposed* Criterion 3 revisions—seven outcomes numbered 1-7. The corresponding provisions of the current EAC

Civil Engineering Program Criteria—though not the subject of this comparison—are nonetheless provided for reference in Column 5. Note that some provisions of the EAC Criteria have been presented out of order to facilitate this side-by-side comparison.

The provisions of EAC Criterion 5 (Curriculum) are *not* student outcomes and thus are not directly comparable to the IEA Graduate Attributes. Nonetheless, some of these provisions do supplement the Criterion 3 Student Outcomes and thus are addressed in a series of notes listed at the bottom of Table 1 and cited, as appropriate, in the individual cells of the table.

Comparison of *Current* ABET EAC Engineering Criteria with IEA Graduate Attributes

To analyze the consistency of the *current* ABET EAC Engineering Criteria with the IEA Graduate Attributes, we compare Columns 2 and 3 of Table 1 for each of the twelve differentiating characteristics in terms of scope, specificity, and cognitive level,^{*} while also accounting for the supplemental information provided in the IEA Knowledge Profile (Appendix B), the IEA Range of Engineering Activities matrix (Appendix C) and the notes addressing EAC Criterion 5. Our specific observations from this comparison are as follows:

- The term *complex problems* is used in eight of the twelve IEA Graduate Attributes (WA1-WA7 and WA10). Taken together with the multi-dimensional definitions provided in the Range of Problem-Solving matrix, the IEA Graduate Attributes provide clear, unambiguous distinctions between engineering, engineering technology, and engineering technician outcomes. Conversely, the corresponding distinctions in the ABET Criteria—reflected in differences between the EAC Criteria for Accrediting Engineering Programs and the ETAC Criteria for Accrediting Engineering Technology Programs—are far less clear.^{15,17}
- With respect to **Engineering Knowledge**, EAC Outcome (a) maps to IEA Graduate Attribute WA1; however, the scope and specificity of EAC Outcome (a) fall short in two significant respects:
 - Through its direct references to Knowledge Profile elements WK1, WK2, and WK3, IEA Attribute WA1 provides valuable descriptions of the types of mathematics, natural sciences, and engineering fundamentals to be applied. Knowledge of the natural sciences and engineering fundamentals is to be systematic and theory-based; and the mathematical knowledge is to include “conceptually-based mathematics, numerical analysis, statistics, and formal aspects of computer and information science to support analysis and modelling....” EAC Outcome (a) simply specifies “knowledge of mathematics, science, and engineering,” with no further clarification or qualification.
 - IEA Attribute WA1 explicitly specifies an engineering specialization, while the EAC Criteria do not. ABET does allow for engineering specialization through the provision of Program Criteria; however, there is no ABET requirement for engineering

^{*} For the purpose of this paper, we use the term “cognitive level” in reference to the level of Bloom’s Taxonomy implied by the verb in an outcome statement. Higher levels of Bloom’s taxonomy imply that higher levels of cognitive development are being targeted.¹⁸

Table 1. Comparison of Current and Proposed EAC Criteria 3 and 5 with the IEA Graduate Attribute Profile for Washington Accord Programs

1	2	3	4	5
Differentiating Characteristic	IEA Graduate Attributes	Current ABET EAC Criterion 3 Outcomes	Proposed ABET EAC Criterion 3 Outcomes	Current EAC Civil Engineering Program Criteria
Engineering Knowledge:	WA1: Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization as specified in WK1 to WK4 respectively to the solution of complex engineering problems.	(a) An ability to apply knowledge of mathematics, science, and engineering.	1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.	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.
Problem Analysis Complexity of analysis	WA2: Identify, formulate, research literature and analyze <i>complex</i> engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences. (WK1 to WK4)	(e) An ability to identify, formulate, and solve engineering problems.		
Design/ development of solutions: Breadth and uniqueness of engineering problems	WA3: Design solutions for <i>complex</i> engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (WK5)	(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. [Note 1]	2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs. [Note 2]	Design a system, component, or process in at least two civil engineering contexts.
Investigation: Breadth and depth of investigation and experimentation	WA4: Conduct investigations of <i>complex</i> problems using research-based knowledge (WK8) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	(b) An ability to design and conduct experiments, as well as to analyze and interpret data.	3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	Conduct experiments in at least two technical areas of civil engineering and analyze and interpret the resulting data.

Modern Tool Usage: Level of understanding of the appropriateness of the tool	WA5: Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to <i>complex</i> engineering problems, with an understanding of the limitations. (WK6)	(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	[Note 3]	
The Engineer and Society: Level of knowledge and responsibility	WA6: Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems. (WK7)	(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context. (j) A knowledge of contemporary issues.	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.	Explain basic concepts in...public policy; and explain the importance of professional licensure.
Environment and Sustainability: Type of solutions.	WA7: Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts. (WK7)			Include principles of sustainability in design.
Ethics: Understanding and level of practice	WA8: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice. (WK7)	(f) An understanding of professional and ethical responsibility.		Analyze issues in professional ethics.
Individual and Team work: Role in and diversity of team	WA9: Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.	(d) An ability to function on multidisciplinary teams.	7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.	Explain basic concepts in... leadership.
Communication: Level of communication according to type of activities performed	WA10: Communicate effectively on <i>complex</i> engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	(g) An ability to communicate effectively.	4. An ability to communicate effectively with a range of audiences.	

Project Management and Finance: Level of management required for differing types of activity	WA11: Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.			Explain basic concepts in project management, business, ... and leadership.
Lifelong Learning: Preparation for and depth of continuing learning.	WA12: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.	(i) A recognition of the need for, and an ability to engage in life-long learning.	6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.	

Notes:

1. Proposed EAC Criterion 5 supplements this outcome by specifying “a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.”
2. The current provision requiring consideration of “constraints such as health and safety, cost, ethics, policy, sustainability, constructability, and manufacturability” has been moved to the Definitions section of the proposed criteria document.
3. The use of modern engineering tools has been moved to proposed EAC Criterion 5. The specific provision is for “one and one-half academic years of engineering topics, consisting of engineering sciences and engineering design appropriate to the program and *utilizing modern engineering tools.*”

specialization.** Furthermore, through Knowledge Profile element WK4, IEA Attribute WA1 sets a very high standard for engineering specialist knowledge—specifying that it “provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline,” with much of this knowledge “at the forefront of the discipline.”

- With respect to **Problem Analysis**, EAC Outcome (e) maps to IEA Graduate Attribute WA2, but its scope and specificity fall short in two respects:
 - IEA Attribute WA2 includes *researching literature* as an integral part of the problem-solving process, while EAC Outcome (e) does not.
 - IEA Attribute WA2 emphasizes applying *first principles* of mathematics, natural sciences and engineering sciences to the solution of problems, while EAC Outcome (e) does not. It is noteworthy that the term “first principles” does not appear in the corresponding Graduate Attributes for Sydney Accord and Dublin Accord programs, thus further sharpening the distinction between engineers, engineering technologists, and engineering technicians.
- With respect to the **Design/Development of Solutions**, EAC Outcome (c) maps to IEA Graduate Attribute WA3, but its scope falls short in one significant respect. EAC Outcome (c) specifies that design is to be performed “within realistic constraints *such as* economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.” The phrase “such as” implies that some *but not all* of these constraints must be considered—a weakness that is not mitigated by the Criterion 5 provision requiring “multiple realistic constraints.” (See Note 1, Table 1.) IEA Attribute WA3 specifies that design is to be performed “with appropriate consideration for public health and safety, cultural, societal, and environmental considerations”—a stronger requirement implying that *all applicable constraints* must be considered.
- With respect to **Investigation**, EAC Outcome (b) maps to IEA Graduate Attribute WA4; however, the scope of EAC Outcome (b) falls short, in that IEA Attribute WA4 encompasses not only experimentation, but also “investigations of complex problems using research-based knowledge and research methods.”
- With respect to **Modern Tool Usage**, EAC Outcome (k) maps to IEA Graduate Attribute WA5 but falls short in both scope and cognitive level, in three significant respects:
 - IEA Attribute WA5 requires the *creation, selection, and application* of modern engineering tools, while EAC Outcome (k) requires only an *ability to use* them.
 - IEA Attribute WA5 explicitly identifies “prediction and modeling” as engineering tools, while EAC Outcome (k) does not.
 - IEA Attribute WA5 explicitly requires an understanding of the *limitations* of modern engineering tools, while EAC Outcome (k) does not.
- With respect to **The Engineer and Society**, EAC Outcomes (h) and (j) map to IEA Graduate Attribute WA6; however, IEA Attribute WA6 provides significantly greater specificity and a higher cognitive level. EAC Outcome (h) specifies a “broad education” and thus is phrased as a curriculum requirement rather than a student outcome; and EAC Outcome (j) requires only the “knowledge of contemporary issues,” independent of any engineering context. Conversely, IEA Attribute WA5 is appropriately phrased as a student outcome, requiring

** According to ABET policy, programs with names that do not correspond to existing Program Criteria are accredited under the General Criteria only. For more information on this “program naming issue” and its implications, see Reference 19.

both a skill (“apply reasoning”) and knowledge (“informed by contextual knowledge”), and appropriately linked to both engineering practice and the solution of complex problems.

- With respect to **Environment and Sustainability**, the IEA Graduate Attribute WA7 requirement to “understand and evaluate... sustainability” has no equivalent in EAC Criterion 3. In EAC Outcome (c), sustainability is included as one of the constraints associated with engineering design; however, because this list of constraints is preceded by “such as,” its inclusion does not constitute a requirement to understand or evaluate sustainability.
- With respect to **Ethics**, EAC Outcome (f) maps to IEA Graduate Attribute WA8 but falls short in the required cognitive level. The IEA Attribute requires that graduates *apply* ethical principles and *commit* to professional ethics, while the EAC Outcome only requires an *understanding* of professional and ethical responsibility. Thus the IEA Attribute is aimed at significantly higher cognitive levels than the EAC Outcome.
- With respect to **Individual and Team Work**, EAC Outcome (d) maps to IEA Graduate Attribute WA9 but falls short in scope. The IEA Attribute requires that graduates function effectively as individuals, and as team members or as leaders in diverse teams. EAC Outcome (d) requires only that graduates function effectively as team members and is silent on diversity.
- With respect to **Communication**, EAC Outcome (g) maps to IEA Graduate Attribute WA10 but falls far short in specificity:
 - IEA Attribute WA10 identifies the relevant *subject* of the required communications—complex engineering activities—while EAC Outcome (g) does not.
 - IEA Attribute WA10 identifies the appropriate *audiences* of the required communications—the engineering community and society at large—while EAC Outcome (g) does not.
 - IEA Attribute WA10 identifies relevant *forms of communication*—reports, design documentation, presentations, and instructions—while EAC Outcome (g) does not.
- With respect to **Project Management and Finance**, IEA Graduate Attribute WA11 has no equivalent in EAC Criterion 3.
- With respect to the **Lifelong Learning**, EAC Outcome (i) maps to IEA Graduate Attribute WA12 but falls short in specificity, with the IEA Attribute specifying an appropriate context for lifelong learning (technological change), while the EAC Outcome does not.

Overall, the current EAC Criteria 3 and 5 can be mapped reasonably well to the IEA Graduate Attributes Profile, but with three significant deficiencies: the EAC Criteria lack any provisions requiring *specialized engineering knowledge* (WA1), understanding and evaluation of *sustainability* (WA7) or understanding of *project management and finance* (WA11). It is also worth noting that, with respect to every one of the remaining nine differentiating characteristics, the Criterion 3 outcomes fall short of the corresponding IEA Attributes in cognitive level, scope, and/or specificity.

Comparison of Proposed ABET EAC Engineering Criteria with IEA Graduate Attributes

Would the proposed changes to EAC Criteria 3 and 5 bring these criteria into closer alignment with the IEA Graduate Attribute Profile? To address this question, we return to Table 1 and compare Column 4 with both Columns 2 and 3, resulting in the following specific observations:

- Proposed EAC Outcome 1 merely combines current EAC Outcomes (a) and (e). This change might appear to increase efficiency with little or no adverse consequence; however, in practice, this change introduces a substantial new inconsistency with the IEA Graduate Attributes. This inconsistency is related to the distinction between *knowledge* and *skill*—a fundamental concept in educational theory.¹⁸ IEA Graduate Attribute WA1 requires the acquisition of a comprehensive, systematic body of mathematical, scientific, and engineering *knowledge*. Attribute WA2 requires the development of a critically important *skill*—the process of solving complex problems. By conflating the two, proposed EAC Outcome 1 muddies this distinction and, in the process, greatly diminishes the importance of the systematic, theory-based body of knowledge that is integral to the engineering profession.
- In proposed EAC Outcome 2, the list of constraints associated with the design process has been relocated to the “Definitions” section of the EAC criteria document. Given that the definitions are located prior to the “General Criteria for Baccalaureate Level Programs” heading, it appears that the definitions are not part of the criteria. Given this placement, it is unclear whether the implied requirement to consider constraints as part of the design process is enforceable. If not, this change would represent a significant new inconsistency between the proposed EAC Criteria and the IEA Graduate Attributes.
- In proposed EAC Outcome 3, the requirement for “an ability to design and conduct experiments” has been changed to “an ability to develop and conduct appropriate experimentation.” Although the distinction between *designing experiments* and *developing experimentation* is not clear, elimination of the word “design” appears to reduce the cognitive level of this outcome and clearly introduces a new inconsistency between the proposed new EAC Criterion 3 and IEA Graduate Attribute WA4.
- Proposed EAC Outcome 4 represents a marginal improvement over current EAC Outcome (g), in that it requires communication *with a range of audiences*. Nonetheless, this outcome still falls far short of IEA Graduate Attribute WA10 in specificity.
- Proposed EAC Outcome 5 represents a significant improvement over current EAC Outcomes (h) and (j), in that it requires that graduates *make informed judgments*, rather than merely *understanding* the societal impact of engineering solutions. However, the resulting improvement in consistency with IEA Graduate Attribute WA6 is compromised, to some extent, by the inclusion of ethics (IEA Attribute WA8) in the same outcome. The authors find the multiple instances of merging outcomes in the proposed EAC Criteria to be quite problematic, as discussed in the Conclusions section below.
- In requiring an ability to “locate, evaluate, integrate, and apply [additional] knowledge appropriately,” proposed EAC Outcome 6 provides a significantly higher degree of specificity than current EAC Outcome (i). Curiously, however, the term “lifelong learning,” specified in both current EAC Outcome (i) and IEA Attribute WA12, has been replaced by the term “additional knowledge” in proposed EAC Outcome 6. Thus an additional inconsistency has been introduced.
- Proposed EAC Outcome 7 eliminates the word *multidisciplinary*. Thus, under this criterion, teams would no longer need to be multi-disciplinary in composition or to function in multi-disciplinary settings—an additional inconsistency with both the current EAC Outcome (i) and IEA Graduate Attribute WA9. EAC Outcome 7 also introduces a series of new competencies—establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty. In the authors’ view, these competencies are entirely appropriate as student outcomes: the first three might be regarded as *skills* associated with management (IEA Attribute WA11)

and the fourth as mathematical *knowledge* (IEA Attribute WA1). However, we question the inclusion of these new competencies in EAC Outcome 7, which is primarily concerned with *teamwork* (IEA Attribute WA9). We also note that the wording of EAC Outcome 7 associates these four competencies with *teams*, even though they are fundamentally *individual* knowledge and skills.

- The proposed EAC Criterion 3 includes no provision for modern tool usage (IEA Graduate Attribute WA5). Current EAC Outcome (k) has been replaced with a new provision in Criterion 5 (Curriculum) requiring “one and one-half academic years of engineering topics, consisting of engineering sciences and engineering design...and *utilizing modern engineering tools*.” Under this revised structure, there is no longer a requirement for students to be able to *use* modern engineering tools (and, hence, for programs to assess this ability); rather, modern engineering tools must merely be included in the curriculum.

In summary, the proposed revision to EAC Criterion 3 provides marginal improvements in consistency with IEA Graduate Attributes WA6 (The Engineer and Society) and WA10 (Communication). However, the revision does not address the two principal deficiencies of the current EAC Criterion 3—lack of any provisions requiring *specialized engineering knowledge* (WA1), understanding and evaluation of *sustainability* (WA7) or understanding of *project management and finance* (WA11). And with respect to all other IEA Attributes, the proposed criteria introduce new inconsistencies.

Conclusions

Based on our comparison of the current and proposed EAC Criteria 3 and 5 with the IEA Graduate Attribute Profile for Washington Accord programs, the authors draw the following conclusions:

- (1) Consistency between the current EAC Criteria 3 and 5 and the IEA Graduate Attribute Profile is weak at best. Unambiguous IEA requirements for specialized engineering knowledge (WA1), understanding and evaluation of sustainability (WA7), and understanding of project management and finance (WA11) are not addressed in current EAC Criteria 3 or 5. And for all of the remaining nine differentiating characteristics, the current EAC Criterion 3 outcomes fall short of the corresponding IEA Attributes in cognitive level, scope, and/or specificity. For example, the current EAC Criterion 3 outcomes do not define the required types of mathematics, science, and engineering knowledge; they do not require consideration of all relevant constraints in engineering design; and they require only an *understanding* of ethical responsibility, rather than a *commitment* to professional ethics.
- (2) It should be noted that the current Civil Engineering Program Criteria do address many of these shortfalls—must notably in the areas of sustainability, project management, and leadership, as indicated in Column 5 of Table 1. However, as we have already noted, ASCE’s inclusion of these non-discipline-specific provisions in its program criteria is an expedient, resulting from the political infeasibility of incorporating them into EAC Criterion 3 over the past decade.
- (3) On the whole, the proposed revisions to EAC Criteria 3 and 5 are *less* consistent with the IEA Graduate Attribute Profile than are the current criteria. Of particular concern is the

relocation of IEA Attribute WA5 (Modern Tool Usage) from the current Criterion 3 to the proposed Criterion 5, where it cannot be assessed as a student outcome.

- (4) The authors are also concerned about the EAC's apparent effort to reduce the number of student outcomes by merging multiple outcomes from the current Criterion 3 into single outcomes in the proposed revision. The IEA Graduate Attribute Profile is organized into twelve *differentiating characteristics* for a reason: these are logically distinct categories, which serve as the basis for defining *individually assessable outcomes*.⁶ Combining two or more of these categories into a single outcome might appear to enhance efficiency; but it is, in fact, a "false economy", because the individual elements must still be assessed separately. More importantly, in the process of merging categories, important distinctions between the categories can be lost—as we noted above in the merging of current EAC Outcomes (a) and (e) to create proposed EAC Outcome 1.
- (5) The IEA Knowledge Profiles and Range of Problem Solving matrix provide a rich supplement to the IEA Graduate Attribute Profiles that greatly clarifies their application. Accreditation criteria that closely follow the structured organization of the IEA Graduate Attribute Profiles would be able to take advantage of these additional resources as well.
- (6) A particularly powerful aspect of the IEA Graduate Attribute Profiles, Knowledge Profiles, and Range of Problem Solving matrix is their clear, consistent, unambiguous differentiation between the competencies required of engineers, engineering technologists, and engineering technicians. Conversely, the distinction between engineering and engineering technology in the current ABET Criteria is considerably less well-defined.²¹
- (7) Finally, in the authors' judgment, the IEA requirement for "engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline," with much of this knowledge "at the forefront of the discipline" is a powerful affirmation of ASCE's "Raise the Bar" initiative, which seeks to achieve an appropriately high level of specialized engineering knowledge by requiring a master's degree or equivalent as the academic prerequisite for professional licensure.

Based on these conclusions, can the ABET EAC Criteria be considered substantially equivalent to the IEA Graduate Attribute Profile for Washington Accord programs? The answer to this question requires a judgment call that depends, to a large extent, on one's interpretation of the term "substantial equivalency." Given this inherent subjectivity, the judgment is best made by experts who are thoroughly versed in the IEA's standards and expectations. As of this writing, an IEA assessment of ABET's compliance with the Washington Accord is underway, and a definitive answer to this question is expected later in 2016.

From the author's perspective, however, there is a more fundamental question: Independent of the IEA's determination on substantial equivalency, *should* the ABET criteria be more closely aligned with the IEA Graduate Attribute Profiles?

Our answer to this question is an unequivocal yes. We suggest that greater consistency between the ABET Accreditation Criteria and the IEA Graduate Attribute Profiles is in the best interest of ABET, the engineering profession, and the public—for the following reasons:

- It will result in improved international mobility for the graduates of ABET-accredited programs.

- It will support ABET’s global initiative—as articulated in the current ABET Strategic Plan²⁰—because non-U.S. accreditation organizations that model their educational quality assurance systems on ABET will be better prepared for eventual membership in the Washington, Sydney, and Dublin Accords.
- Most importantly, it will improve the quality of engineering education in the U.S. As this paper has demonstrated, the IEA Graduate Attribute Profiles consistently exceed the ABET Criteria in rigor, comprehensiveness, coherence, and specificity. Programs that comply more fully with the IEA Graduate Attributes will produce graduates with higher levels of knowledge and skill.

Recommendations

Consistent with these conclusions, the authors recommend:

- That ASCE not support ABET’s proposed revision to EAC Criteria 3 and 5.
- That ASCE advocate for a new formulation of EAC Criteria 3 and 5 that brings the criteria into the closest feasible alignment with the IEA Graduate Attributes.
- That future editions of the Civil Engineering Body of Knowledge and the Civil Engineering Technology Body of Knowledge use the IEA Graduate Attributes Profile as a major source of input—to include adopting the twelve IEA differentiating characteristics as an organizing construct and adopting the IEA Range of Problem-Solving as a means of differentiating the roles of engineers, engineering technologists, and engineering technicians.

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Appendix A – IEA Graduate Attribute Profiles

Differentiating Characteristic	... for Washington Accord Graduate	... for Sydney Accord Graduate	... for Dublin Accord Graduate
Engineering Knowledge	WA1: Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization as specified in WK1 to WK4 respectively to the solution of complex engineering problems.	SA1: Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization as specified in SK1 to SK4 respectively to defined and applied engineering procedures, processes, systems or methodologies.	DA1: Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization as specified in DK1 to DK4 respectively to wide practical procedures and practices.
Problem Analysis: Complexity of analysis	WA2: Identify, formulate, research literature and analyze <i>complex</i> engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences. (WK1 to WK4)	SA2: Identify, formulate, research literature and analyze <i>broadly-defined</i> engineering problems reaching substantiated conclusions using analytical tools appropriate to the discipline or area of specialization. (SK1 to SK4)	DA2: Identify and analyze <i>well-defined</i> engineering problems reaching substantiated conclusions using codified methods of analysis specific to their field of activity. (DK1 to DK4)
Design/Development of Solutions: Breadth and uniqueness of engineering problems i.e. the extent to which problems are original and to which solutions have previously been identified or codified	WA3: Design solutions for <i>complex</i> engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (WK5)	SA3: Design solutions for <i>broadly-defined</i> engineering technology problems and <i>contribute to</i> the design of systems, components or processes to meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (SK5)	DA3: Design solutions for <i>well-defined</i> technical problems and <i>assist with</i> the design of systems, components or processes to meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (DK5)
Investigation: Breadth and depth of investigation and experimentation	WA4: Conduct investigations of <i>complex</i> problems using research-based knowledge (WK8) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	SA4: Conduct investigations of <i>broadly-defined</i> problems; locate, search and select relevant data from codes, data bases and literature (SK8), design and conduct experiments to provide valid conclusions.	DA4: Conduct investigations of <i>well-defined</i> problems; locate and search relevant codes and catalogues, conduct standard tests and measurements.
Modern Tool Usage: Level of understanding of the appropriateness of the tool	WA5: Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to <i>complex</i> engineering problems, with an understanding of the limitations. (WK6)	SA5: Select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to <i>broadly-defined</i> engineering problems, with an understanding of the limitations. (SK6)	DA5: Apply appropriate techniques, resources, and modern engineering and IT tools to <i>well-defined</i> engineering problems, with an awareness of the limitations. (DK6)

The Engineer and Society: Level of knowledge and responsibility	WA6: Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems. (WK7)	SA6: Demonstrate understanding of the societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to engineering technology practice and solutions to broadly defined engineering problems. (SK7)	DA6: Demonstrate knowledge of the societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to engineering technician practice and solutions to well defined engineering problems. (DK7)
Environment and Sustainability: Type of solutions.	WA7: Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts. (WK7)	SA7: Understand and evaluate the sustainability and impact of engineering technology work in the solution of broadly defined engineering problems in societal and environmental contexts. (SK7)	DA7: Understand and evaluate the sustainability and impact of engineering technician work in the solution of well defined engineering problems in societal and environmental contexts. (DK7)
Ethics: Understanding and level of practice	WA8: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice. (WK7)	SA8: Understand and commit to professional ethics and responsibilities and norms of engineering technology practice. (SK7)	DA8: Understand and commit to professional ethics and responsibilities and norms of technician practice. (DK7)
Individual and Team work: Role in and diversity of team	WA9: Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.	SA9: Function effectively as an individual, and as a member or leader in diverse teams.	DA9: Function effectively as an individual, and as a member in diverse technical teams.
Communication: Level of communication according to type of activities performed	WA10: Communicate effectively on <i>complex</i> engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	SA10: Communicate effectively on <i>broadly-defined</i> engineering activities with the engineering community and with society at large, by being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions	DA10: Communicate effectively on <i>well-defined</i> engineering activities with the engineering community and with society at large, by being able to comprehend the work of others, document their own work, and give and receive clear instructions
Project Management and Finance: Level of management required for differing types of activity	WA11: Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	SA11: Demonstrate knowledge and understanding of engineering management principles and apply these to one's own work, as a member or leader in a team and to manage projects in multidisciplinary environments.	DA11: Demonstrate knowledge and understanding of engineering management principles and apply these to one's own work, as a member or leader in a technical team and to manage projects in multidisciplinary environments
Lifelong learning: Preparation for and depth of continuing learning.	WA12: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.	SA12: Recognize the need for, and have the ability to engage in independent and life-long learning in specialist technologies.	DA12: Recognize the need for, and have the ability to engage in independent updating in the context of specialized technical knowledge.

Appendix B – IEA Knowledge Profile

A Washington Accord program provides:	A Sydney Accord program provides:	A Dublin Accord program provides:
WK1: A systematic, theory-based understanding of the natural sciences applicable to the discipline	SK1: A systematic, theory-based understanding of the natural sciences applicable to the sub-discipline	DK1: A descriptive, formula-based understanding of the natural sciences applicable in a sub-discipline
WK2: Conceptually-based mathematics , numerical analysis, statistics and formal aspects of computer and information science to support analysis and modeling applicable to the discipline	SK2: Conceptually-based mathematics , numerical analysis, statistics and aspects of computer and information science to support analysis and use of models applicable to the sub-discipline	DK2: Procedural mathematics , numerical analysis, statistics applicable in a sub-discipline
WK3: A systematic , theory-based formulation of engineering fundamentals required in the engineering discipline	SK3: A systematic, theory-based formulation of engineering fundamentals required in an accepted sub-discipline	DK3: A coherent procedural formulation of engineering fundamentals required in an accepted sub-discipline
WK4: Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.	SK4: Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for an accepted sub-discipline	DK4: Engineering specialist knowledge that provides the body of knowledge for an accepted sub-discipline
WK5: Knowledge that supports engineering design in a practice area	SK5: Knowledge that supports engineering design using the technologies of a practice area	DK5: Knowledge that supports engineering design based on the techniques and procedures of a practice area
WK6: Knowledge of engineering practice (technology) in the practice areas in the engineering discipline	SK6: Knowledge of engineering technologies applicable in the sub-discipline	DK6: Codified practical engineering knowledge in recognized practice area.
WK7: Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the professional responsibility of an engineer to public safety; the impacts of engineering activity: economic, social, cultural, environmental and sustainability	SK7: Comprehension of the role of technology in society and identified issues in applying engineering technology: ethics and impacts: economic, social, environmental and sustainability	DK7: Knowledge of issues and approaches in engineering technician practice: ethics, financial, cultural, environmental and sustainability impacts
WK8: Engagement with selected knowledge in the research literature of the discipline	SK8: Engagement with the technological literature of the discipline	
A program that builds this type of knowledge and develops the attributes listed below is typically achieved in 4 to 5 years of study, depending on the level of students at entry.	A program that builds this type of knowledge and develops the attributes listed below is typically achieved in 3 to 4 years of study, depending on the level of students at entry.	A program that builds this type of knowledge and develops the attributes listed below is typically achieved in 2 to 3 years of study, depending on the level of students at entry.

Appendix C – IEA Range of Problem Solving

Attribute	<i>Complex Engineering Problems</i> have characteristic WP1 and some or all of WP2 to WP7:	<i>Broadly-defined Engineering Problems</i> have characteristic SP1 and some or all of SP2 to SP7:	<i>Well-defined Engineering Problems</i> have characteristic DP1 and some or all of DP2 to DP7:
Depth of Knowledge Required	WP1: Cannot be resolved without in-depth engineering knowledge at the level of one or more of WK3, WK4, WK5, WK6 or WK8 which allows a fundamentals-based, first principles analytical approach	SP1: Cannot be resolved without engineering knowledge at the level of one or more of SK 4, SK5, and SK6 supported by SK3 with a strong emphasis on the application of developed technology	DP1: Cannot be resolved without extensive practical knowledge as reflected in DK5 and DK6 supported by theoretical knowledge defined in DK3 and DK4
Range of conflicting requirements	WP2: Involve wide-ranging or conflicting technical, engineering and other issues	SP2: Involve a variety of factors which may impose conflicting constraints	DP2: Involve several issues, but with few of these exerting conflicting constraints
Depth of analysis required	WP3: Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	SP3: Can be solved by application of well-proven analysis techniques	DP3: Can be solved in standardised ways
Familiarity of issues	WP4: Involve infrequently encountered issues	SP4: Belong to families of familiar problems which are solved in well-accepted ways	DP4: Are frequently encountered and thus familiar to most practitioners in the practice area
Extent of applicable codes	WP5: Are outside problems encompassed by standards and codes of practice for professional engineering	SP5: May be partially outside those encompassed by standards or codes of practice	DP5: Are encompassed by standards and/or documented codes of practice
Extent of stakeholder involvement and conflicting requirements	WP6: Involve diverse groups of stakeholders with widely varying needs	SP6: Involve several groups of stakeholders with differing and occasionally conflicting needs	DP6: Involve a limited range of stakeholders with differing needs
Interdependence	WP 7: Are high level problems including many component parts or sub-problems	SP7: Are parts of, or systems within complex engineering problems	DP7: Are discrete components of engineering systems
<i>In addition, in the context of the Professional Competencies</i>			
Consequences	EP1: Have significant consequences in a range of contexts	TP1: Have consequences which are important locally, but may extend more widely	NP1: Have consequences which are locally important and not far-reaching
Judgement	EP2: Require judgement in decision making	TP2: Require judgement in decision making	