AC 2008-667: FOUNDATIONAL OUTCOMES OF THE NEW CIVIL ENGINEERING BODY OF KNOWLEDGE

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Foundational Outcomes of the
New Civil Engineering Body of Knowledge

Abstract

The new civil engineering Body of Knowledge (BOK2) identifies three categories of outcomes as follows: Foundational, Technical and Professional. The four Foundational outcomes are Mathematics, Natural Sciences, Humanities and Social Sciences. This paper explores background, philosophy, intent and goals of the four Foundational outcomes.

These four Foundational outcomes recognize that the careers of future civil engineers need to be underpinned by all -- not only Mathematics and Natural Sciences but Humanities and Social Sciences as well. Civil Engineering is a technical discipline and the strong technical education must continue, but it also must be recognized that the contributions of civil engineers are largely to and for human society. The Humanities includes subjects such as art, philosophy and literature while the Social Sciences include subjects such as political science, economics, sociology and psychology. BOK2 continues to recognize the need for education in Mathematics and Natural Sciences but now also explicitly recognizes the foundational importance of Humanities and Social Sciences.

The four outcomes in the Foundational category underpin the remaining technical and professional outcomes as well as form the basis for a well-educated civil engineer of the 21st century. They align with the four core areas of liberal learning (learning that frees the mind from constrained thinking): Mathematics, Natural Sciences, Humanities and Social Sciences. The education of civil engineers formerly emphasized Mathematics and Natural Sciences and the first edition of the Body of Knowledge (BOK1) has three outcomes for these two areas including one each for Mathematics, Chemistry and Physics. There are no specific outcomes for Humanities or Social Sciences in BOK1. The new Civil Engineering BOK2 recognizes the importance of the four foundational areas of knowledge and four outcomes have been adopted, one for each of the core foundational areas.

Introduction

The National Academy of Engineering Report, *The Engineer of 2020*[1], identifies these three visions for the engineering profession:

- *By 2020, we aspire to a public that will understand and appreciate the profound impact of the influence of the engineering profession on socio-cultural systems, the full spectrum of career opportunities accessible through an engineering education, and the value of an engineering education to engineers working successfully in non-engineering jobs.*

- *We aspire to a public that will recognize the union of professionalism, technical knowledge, social and historical awareness, and traditions that serve to make engineers competent to address the world's complex and changing challenges.*
- *We aspire to engineers who will remain well grounded in the basics of mathematics and science, and who will expand their vision of design through solid grounding in the humanities, social sciences, and economics. Emphasis on the creative process will allow more effective leadership in the development and application of next-generation technologies to problems of the future.*

Fulfillment of the engineering vision requires professional activity supported on a balanced base of liberal learning. Failure to provide engineers with an education founded upon this balanced base will compromise the profession's ability to realize this vision, to recruit and retain the best talent, and to perform effectively as a profession. This concept is broadly shared among other professions (e.g., law, medicine, and architecture).

In a recent report reinforcing this thesis, *Engineering for a Changing World*[2], Duderstadt notes that *…the key to producing such world-class engineers is to take advantage of the fact that the comprehensive nature of American universities provide the opportunity for significantly broadening the educational experience of the engineering students, provided that engineering schools, accreditation agencies such as ABET, the profession and the marketplace are willing to embrace such an objective. Essentially all other learned professions have long ago moved in this direction (law, medicine, business, architecture) requiring a broad liberal arts baccalaureate education as a prerequisite for professional education at the graduate level.*

The process of developing the newly released Body of Knowledge for the 21st Century, Second Edition[3] (BOK2) allowed those involved to consider feedback from a wide constituency and to rethink the nature of the outcomes that are needed to educate the civil engineer for the future as well as the organization of these outcomes. The first edition (BOK1)[4] listed outcomes without organizing them using any particular ontology. Further BOK1 did not intentionally and explicitly require studies in the Humanities or Social Sciences but rather identified the requirement for the "broad education necessary…". As a result of the BOK2 process, substantial (some might say radical) advancements were made in the recognition of the role of Humanities and Social Sciences in engineering education. With this, there was further recognition that outcomes could be classified as Foundational, Technical or Professional.

A Balanced Body of Knowledge

The central idea of a broad education is displayed graphically in Figure 1, showing technical and professional education and performance supported by four Foundational legs (Mathematics, Natural Sciences, Humanities, Social Sciences). Each leg is logically different. Together these broadly illustrate the established dimensions of higher education.

The 20th century has seen a major expansion in the Mathematics and Science "legs" that support civil engineering. The continuing importance of this is emphasized by the inclusion of four separate outcomes in BOK2 and the strong reliance of other outcomes on these Mathematics and Natural Science foundations.

An absence of explicit support legs for Humanities and Social Sciences would be consistent with the classical impression of an engineer well-grounded only in technical issues. This is an unfortunate historical stereotype, one that the profession largely rejects today and aspires to move beyond. Accordingly, separate support legs for Humanities and for Social Sciences are included in BOK2. All four legs are essential in supporting the vision of the civil engineering profession.

Relative to these legs, Vest,[5,6] identifies two "pivotal" developments in engineering education since World War II: the development of the science base of "engineering science"; and the incorporation of the H&SS in support of the "twenty-first-century view of engineering systems, which surely are not based solely on physics and chemistry." Note the increasing reliance on the Humanities leg and Social Sciences leg and the obligation to develop these within the profession broadly, as a matter of basic professional competence.

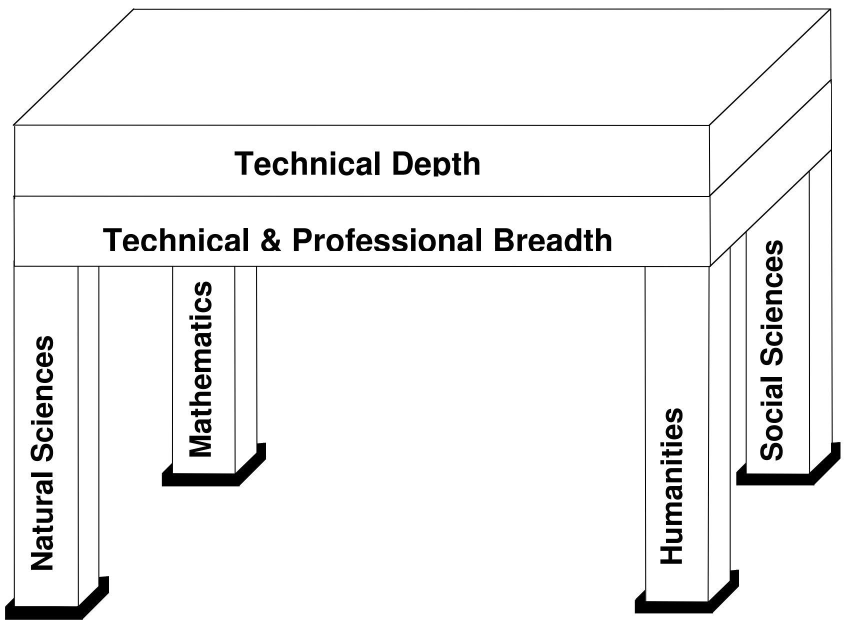

Figure 1: The future technical and professional practice education of civil engineers is supported on four foundational legs

Foundations of Civil Engineering Education

Four Foundational outcomes have been articulated in BOK2. The four are Mathematics, Natural Sciences, Humanities and Social Sciences. Why these four? In a statement by the Association of American Colleges and Universities[7], liberal learning is defined as:

> *A truly liberal education is one that prepares us to live responsible, productive, and creative lives in a dramatically changing world. It is an education that fosters a well-grounded intellectual resilience, a disposition toward lifelong learning, and an acceptance of responsibility for the ethical consequences of our ideas and actions.*

Liberal education requires that we understand the foundations of knowledge and inquiry about nature, culture and society; that we master core skills of perception, analysis, and expression; that we cultivate a respect for truth; that we recognize the importance of historical and cultural context; and that we explore connections among formal learning, citizenship, and service to our communities.
We experience the benefits of liberal learning by pursuing intellectual work that is honest, challenging, and significant, and by preparing ourselves to use knowledge and power in responsible ways. Liberal learning is not confined to particular fields of study. What matters in liberal education is substantial content, rigorous methodology and an active engagement with the societal, ethical, and practical implications of our learning. The spirit and value of liberal learning are equally relevant to all forms of higher education and to all students.

While civil engineers do not normally consider their education to be a liberal education, it is time to rethink the conventional view of civil engineering education. A careful read of the above reveals that our profession, that which serves society and its people, needs practicing professionals that indeed have received an education with *substantial content, rigorous methodology and an active engagement with the societal, ethical, and practical implications* of their learning.

What then is the foundation of a liberal education? A liberal education is one that liberates, that is, one that frees the learner *from the constraints of ignorance, sectarianism, and myopia; it prizes curiosity and seeks to expand the boundaries of human knowledge.*[8] It is *not* an ideological or political category. While the origin, and even the current constitution of a liberal arts education are wholly agreed upon, the term *artes liberalis* is medieval in origin and relates to the education for a freeman and was contrasted to that training considered vocational. The term captures earlier classifications of *Trivium* which included grammar, rhetoric and logic and *Quadrivium* which included arithmetic, geometry, astronomy and music. In this context, *Logic is the art of thinking; grammar, the art of inventing symbols and combining them to express thought; and rhetoric, the art of communicating thought from one mind to another, the adaptation of language to circumstance.*[9] While these outcomes go back hundreds of years, it is clear the civil engineer of the future must possess these skills.

In more modern terms, these foundations of education can be captured by the Body of Knowledge in the categories of Mathematics, Natural Science, Humanities and Social Science. While engineers intuitively understand what constitutes Mathematics, a dictionary definition is useful for completeness. Mathematics is: *the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions and of space configurations and their structure, measurement, transformations, and generalizations.*[10] Arithmetic, algebra, geometry, trigonometry, calculus and differential equations are branches of mathematics. Similarly, engineers are familiar with natural sciences as defined by: *any of the sciences (as physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformations or with objectively measurable phenomena.*[11] Humanities includes subjects such as art, philosophy, languages and literature that investigate human constructs and concerns. Social Science includes subjects such as political science, economics, sociology and psychology that deal with the functioning of society and its institutions. Social Sciences are often data-driven and quantitative while humanities typically employ critical and analytic thinking.

The need for a solid foundation in civil engineering education is supported by the concepts of liberal learning above and in the concepts of critical thinking. Civil engineers think about and develop solutions to problems. A civil engineer's thinking must be systematic and guided and informed by analysis and assessment of relevant information. A civil engineer's thinking must not be arbitrary, biased, lacking in context, or poorly substantiated. A critical thinker:[12c]

- *raises vital questions and problems, formulating them clearly and precisely;*
- *gathers and assesses relevant information, using abstract ideas to interpret it effectively, comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards;*
- *thinks open-mindedly in consideration of alternative solutions, recognizing and assessing, as need be, their assumptions, implications, and practical consequences; and*
- *communicates effectively with others in figuring out solutions to complex problems.*

For civil engineers educated largely in areas of Mathematics and Natural Science, the most prominent questions are likely to be perceived as mathematical and scientific questions. Alternatively, a civil engineer whose education includes all four foundational areas will bring more to the critical thinking process. A broadly-educated engineer is likely to recognize the impact of the engineering decisions upon the more broadly-framed questions informed by Mathematics, Natural Science, Humanities and Social Sciences. (S)he is positioned to perceive the engineering problem as one of *delivering* technological services *to* humans, *through* social institutions, creatively. Creativity is necessary with the service itself, with its technological basis, and with its social realization.

Foundational Outcomes

In order to recognize the importance of Mathematics, Natural Sciences, Humanities and Social Sciences in the education of future civil engineers, in BOK2 outcomes were consolidated, rearranged and two new outcomes, one for Humanities and one for Social Sciences have been included. There is considerable freedom for educators to determine how these outcomes may be fulfilled through contributions from various academic departments and disciplines. This freedom permits each program to devise requirements consistent with their university and department missions. The level of achievement of each outcome is defined in terms of Level 3, Application, of Blooms Taxonomy. Each of these outcomes is expected to be achieved during the Bachelors education. The implementation of this approach is through the four Foundational Outcomes from BOK2 summarized in Table 1 and discussed in this section.

Table 1: Foundational Outcomes in BOK2

Outcome number and title	To enter the practice of civil engineering at the professional level, an individual must be able to demonstrate this level of achievement
Foundational Outcomes	
1 Mathematics	***Solve*** problems in mathematics through differential equations and ***apply*** this knowledge to the solution of engineering problems. **(L3)**
2 Natural sciences	***Solve*** problems in calculus-based physics, chemistry, and one additional area of natural science and ***apply*** this knowledge to the solution of engineering problems. **(L3)**
3 Humanities	***Demonstrate*** the importance of the humanities in the professional practice of engineering **(L3)**
4 Social sciences	***Demonstrate*** the incorporation of social sciences knowledge into the professional practice of engineering. **(L3)**

Outcome 1: Mathematics

Mathematics deals with the science of structure, order, and relation that has evolved from counting, measuring, and describing the shapes of objects. It uses logical reasoning and quantitative calculation. Since the 17th century, Mathematics has been an indispensable adjunct to the physical sciences and technology, and is considered the underlying language of science. The principal branches of Mathematics relevant to civil engineering are algebra, analysis, arithmetic, geometry, calculus, numerical analysis, optimization, probability, set theory, statistics, and trigonometry.

All areas of civil engineering rely on Mathematics for performing quantitative analysis of engineering systems. A technical core of knowledge and breadth of coverage in Mathematics, and the ability to apply it to solve engineering problems, are essential for civil engineers. To enter the practice of civil engineering at the professional level, an individual must be able to: ***Solve* problems in Mathematics through differential equations and *apply* this knowledge to the solution of engineering problems.** The Mathematics required for civil engineering practice must be learned at the undergraduate level and should prepare students for subsequent courses in engineering curricula.

Outcome 2: Natural Sciences

Underlying the professional role of the civil engineer as the master integrator and technical leader is a firm foundation in the Natural Sciences. Physics and chemistry are two disciplines of Natural Sciences that have historically served as basic foundations. Additional disciplines of Natural Science also are assuming stronger roles within civil engineering.

Physics is concerned with understanding the structure of the natural world and explaining natural phenomena in a fundamental way in terms of elementary principles and laws. The fundamentals of physics are mechanics and field theory. Mechanics is concerned with the equilibrium and motion of particles or bodies under the action of given forces. The physics of fields encompasses the origin, nature, and properties of gravitational, electromagnetic, nuclear, and other force fields. Taken together, mechanics and field theory constitute the most fundamental approach to an understanding of natural phenomena which science offers. Physics is characterized by accurate instrumentation, precision of measurement, and the expression of its results in mathematical terms. Many areas of civil engineering rely on physics for understanding the underlying governing principles and for obtaining solutions to problems. A technical core of knowledge and breadth of coverage in physics, and the ability to apply it to solve engineering problems, are essential for civil engineers.

Chemistry is the science that deals with the properties, composition, and structure of substances (elements and compounds), the reactions and transformations they undergo, and the energy released or absorbed during those processes. Chemistry is concerned with atoms as building blocks, everything in the material world, and all living things. Branches of chemistry include inorganic, organic, physical, and analytical chemistry; biochemistry; electrochemistry; and geochemistry. Some areas of civil engineering, especially environmental engineering and construction materials, rely on chemistry for explaining phenomena and obtaining solutions to problems. A technical core of knowledge and breadth of coverage in chemistry is necessary for individuals to solve related problems in civil and environmental engineering.

Additional breadth in Natural Science disciplines such as biology, ecology, geology/geomorphology, etc. is required to prepare the civil engineer of the future. Increased exposure to or emphasis on biological systems, ecology, sustainability, and nanotechnology is expected to occur in the 21st century. Civil engineers should have the basic scientific literacy that will allow them to be conversant with technical issues pertaining to environmental systems, public health and safety, durability of construction materials, and other such subjects. A technical core of knowledge and breadth of coverage in an area of science other than mathematics, physics, and chemistry is required to prepare future civil engineers.

To enter the practice of civil engineering at the professional level, an individual must be able to: ***Solve*** **problems in calculus-based physics, chemistry, and one additional area of Natural Science and *apply* this knowledge to the solution of engineering problems.** The physics, chemistry, and breadth in Natural Sciences required for civil engineering practice must be learned at the undergraduate level and should prepare students for subsequent courses in engineering and engineering practice.

Outcome 3: Humanities

To be effective, professional civil engineers must be critical thinkers with the ability to raise vital questions and problems, and formulate them clearly and appropriately. They must gather and assess relevant information, use abstract ideas to interpret the information effectively, and come to well-reasoned conclusions and solutions, testing them against relevant criteria and standards. Professional civil engineers must think open-mindedly within alternative systems of thought, recognizing and assessing, as need be, the assumptions, implications, and practical consequences of their work. They must be informed by not only Mathematics and the Natural and Social Sciences, but by the humanities, the disciplines that study the human aspects of the world such as philosophy, history, literature, visual arts, performing arts, language and religion. Humanities are academic disciplines which use critical or speculative methods to study the human condition. This outcome is intended to guide students to understand the importance of the humanities on the professional practice of engineering. This understanding is critical to professional delivery of service *to people*.

The formal education process sets the stage for professional achievement. In practice, our profession involves varying degrees of integration of humanities such as ethical, aesthetic, and historical factors. Engineers must be able to recognize and incorporate these human factors into the development and evaluation of solutions to engineering and societal problems. Continued development of professional competence must come from life-long learning, mentorship from senior engineers, practical experience, and involvement with the local community, grounded on a firm foundation in, and recognition of the importance of, the humanities.

To enter the practice of civil engineering at the professional level, an individual must be able to: ***Demonstrate* the importance of the humanities in the professional practice of engineering.** The formal education process at the undergraduate level must include the humanities in order for the student to develop an appreciation of their importance in developing engineering solutions. All students cannot study all of the humanities; rather, students first must be able to recognize and identify factual information from more than one area of the humanities. Students should be able to explain concepts in at least one area of humanities in order for them to explain how this can inform and impact their engineering decisions. Students should be able to apply their knowledge of humanities by demonstrating the importance of the humanities on the professional practice of engineering. Examples of opportunities to demonstrate this ability include incorporating application of philosophy in engineering ethics, visual arts in the aesthetics of structures, language in the globalization of engineering, and history in the study of the past accomplishments of society through civil engineering.

Outcome 4: Social Sciences

Engineering services are delivered through social mechanisms and institutions. The Social Sciences are the systematic study of these. Example disciplines include economics, political science, sociology, and psychology. (Note that some studies in history are categorized as social sciences.) Social sciences are by definition scientific: quantitative, analytical, and data-driven and use the scientific method including both qualitative and quantitative methods. Professional civil engineers must work within a social framework; understanding it is foundational to effective professionalism, alongside the three other foundational areas (i.e., Mathematics, Natural Sciences, and Humanities). This outcome is intended to guide students to make connections between their technical education and their education in the Social Sciences. Effective delivery of professional service depends critically upon these connections.

The formal education process sets the stage for individuals to become effective professionals. In practice, virtually all projects and design work involve varying degrees of integration of social sciences knowledge, such as economic and socio-political aspects. Engineers must be able to recognize and incorporate these considerations into the development, delivery, and evaluation of solutions to engineering problems. Continued development of professional competence must come from life-long learning, mentorship from senior engineers, and practical experience, grounded on a firm foundation in, and recognition of, the importance of the Social Sciences and advances in them.

To enter the practice of civil engineering at the professional level, an individual must be able to: ***Demonstrate* the incorporation of Social Sciences knowledge into the professional practice of engineering.** The formal education process at the undergraduate level must include an introduction to social sciences in order for the student to develop an appreciation of their importance in the development of engineering solutions. All students cannot master all of the social sciences; rather, students first must be able to recognize and identify factual information in more than one area of social science. Students should be able to explain the concepts in at least one area of Social Science in order for them to explain how this area of Social Science can inform their engineering decisions. Students should be able to apply their knowledge of Social Sciences by demonstrating its incorporation into the professional practice of engineering. Examples of knowledge from Social Sciences that might be applied in engineering include economic, safety and security, or environmental considerations. Examples of opportunities to demonstrate this ability includes incorporating application of Social Sciences in engineering courses such as transportation, environmental engineering, capstone, or major design experience.

Summary

In order to recognize the importance of Mathematics, Natural Sciences, Humanities and Social Sciences in the education of future civil engineers, BOK2 has reorganized and consolidated existing Mathematics and Natural Sciences outcomes from BOK and added two new outcomes, one for Humanities and one for Social Sciences. Each of the four legs is logically distinct, an independent branch of learning and supporting professional achievement in unique ways. There is considerable freedom for educators to determine how these outcomes may be fulfilled through contributions from various academic departments and disciplines. This freedom permits each program to devise requirements consistent with their university and department missions. Experimentation and creative implementation of these Foundational Outcomes is encouraged. It is important to stress foundational outcomes as part of preparing a professional for this century and to integrate the Foundational Outcomes across the Professional and Technical Outcomes. An aggressive approach among providers and accreditors is necessary as the vision of engineering in 2020 involves students in the classroom today.

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