Two Comprehensive U.S. Studies of Engineering Education Reform

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Abstract – **Two detailed studies of engineering education reform have recently been undertaken by major engineering organizations in the U.S.A. The impetus for both was a realization that major changes in engineering education were needed to meet 21st century challenges. Both studies broadly recognized that engineering education must be reformed; otherwise, American engineers will be ill-prepared to meet global challenges. The studies were by the American Society of Civil Engineering (ASCE) and the U.S. National Academy of Engineering (NAE). The authors were involved in both studies. ASCE's call for action led to ASCE Policy Statement 465 which states that in the future, education beyond the baccalaureate degree will be necessary for entry into civil engineering professional practice. One prime result of the study was development of the Body of Knowledge (BOK) for civil engineering. The NAE "Engineer of 2020" study was initiated in 2000. Phase I focused on the nature of future engineering practice and Phase II on changes needed in engineering education if future challenges are to be met. Recommendations included that the master's degree be the accepted first professional degree for engineers.**

Index Terms – Body of knowledge, dual-level accreditation, engineering education reform, first professional degree.

INTRODUCTION

Reformation of engineering education has been talked about for many decades in the United States. But, while changes have been made on the edges, no major reform has occurred, particularly in relation to strengthening the leadership and other professional skills of the engineers. Seely presents the history of this reform movement through the 20th century [1]. Noteworthy are the periodic reports that have been issued emphasizing the need for engineering education reform beginning with the Mann Report of 1918. Seely identified nine other significant reports published from 1930 to 1989 that stressed the need for reform. The two studies discussed herein are more comprehensive and focus on global challenges of engineers.

American civil engineers through the proceedings of the six American Society of Civil Engineers (ASCE) Education Conferences from 1960 through 1995 also addressed the reform issue [2]. As a result of the last conference ASCE's Board of Direction adopted a policy that essentially stated, "*ASCE supports the concept of a master's degree or equivalent as a requirement for licensure and the practice of civil engineering at the professional level.*" This was refined in 2004 to read: "*The ASCE supports the attainment of a Body of Knowledge for entry into the practice of civil engineering at the professional level.*" The focus was on the knowledge needed for future successful professional practice as exemplified in the ASCE Body of Knowledge (BOK), i.e., *The knowledge, skills, and attitudes necessary for successful practice.* It takes a more global view of engineering giving more attention to professional skills as well as the traditional technical skills.

The 2004 initial ASCE Body of Knowledge report, identified 15 broad educational outcomes necessary. These included 11 outcomes similar to those accreditation outcomes of the Accreditation Board for Engineering and Technology, Inc. (ABET), i.e., Criterion 3 outcomes [3] – and four additional outcomes specific to civil engineering.

Concurrent with the Body of Knowledge efforts, the Board-level ASCE Committee on Academic Prerequisites for Professional Practice (CAP^3) and associated constituent committees to address other issues associated with successful implementation of ASCE's policy were formed. These included committees on Licensure, Curriculum, Levels of Achievement, Fulfillment and Validation, and Accreditation – in addition to the BOK. The CAP^3 committee coordinated with other relevant ASCE committees.

At the present time, the 2nd edition of the Body of Knowledge report is being compiled. Key differences from the 1st edition of the BOK include a more structured approach to defining achievement levels for each of the educational outcomes using the well known Bloom's Taxonomy, and better definition of outcomes included in the BOK [4,5].

HISTORICAL PERSPECTIVE

Engineers have been advocating reform of engineering education for nearly a century as outlined by Seely [1]. It is

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important "…to remember that until the end of the nineteenth century, the primary means by which a young man (then it was a male dominated profession) became an engineer was

through a hands-on apprenticeship in a machine shop, at a drawing board, behind a transit, or on a construction site." At the end of the 19th century, a formal collegiate education emerged as the predominant method of developing and educating engineers.

As the education of engineers moved into the classroom, the tug-of-war between theory and practice, technical subject matter versus a broad liberal education, and engineering design versus engineering science began being debated. The "…early debates were loud and prolonged, despite calls for changes as early as the 1880s by leading engineers, such as Robert Thurston of Cornell University. The most famous U.S. study of engineering education – the Wickenden report of the 1920s – also called for less hands-on specialization and more general preparation in math and science. These debates have continued and now include topics such as communication skills, basic math and science content, hands-on courses versus theoretical topics, and fundamental versus applied research. Also, the issue of professional skills (project management, economics, business savvy, and understanding the global context of engineering practice) has emerged.

In 1900, engineering led other professions in formal education requirements, with a four-year baccalaureate degree necessary for entry into the profession. As the decades passed, engineering steadfastly maintained that four years was sufficient for professional practice. However, other professions, such as medicine and law responded to changes in society and increased the knowledge practitioners needed. Figure 1 illustrates the changes – engineering was being left behind.

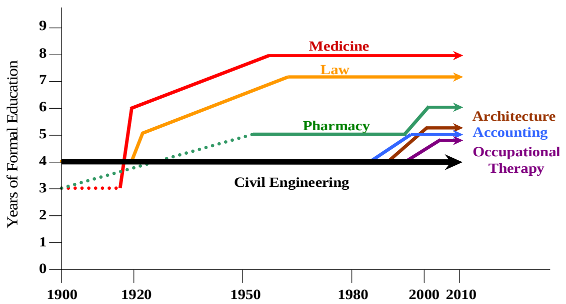

FIGURE 1
YEARS OF FORMAL EDUCATION REQUIRED TO ENTER THE PROFESSION [6]

Arguably, the increase in the engineering Body of Knowledge has been as large, and maybe larger, than several other professions. Yet, with few temporary exceptions, the engineering schools maintained their four-year programs. Three universities, Cornell, Minnesota and Ohio State, quietly dropped their five-year undergraduate programs and reverted back to the traditional four-year undergraduate program when it became apparent they were leaders with no followers [1].

In addition, pressure has been to reduce the credit hours for the engineering degree to reduce the cost of education. This reduction is exemplified in Figure 2 which shows the trend line of semester credit hours required for graduation since the early 1900s.

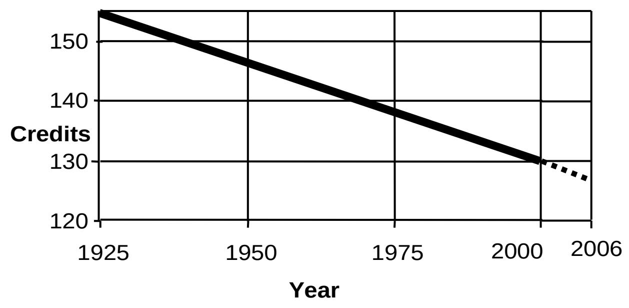

FIGURE 2
CREDIT HOURS FOR GRADUATION [7]

The combination of the increase in the requisite civil engineering body of knowledge, technical specialization, and the reduction in credit hours produced what some viewed as a crisis in civil engineering education. ASCE, as the voice of the profession, led in addressing this issue. As a direct result, the ASCE Board-level Task Committee on Civil Engineering Education Initiatives (TCEEI) was approved in 1995 "…to champion implementation of educational initiatives deriving from the 1995 Civil Engineering Education Conference" [2].

Recommendations in the committee's report to the Board led to the 1998 adoption of the initial version of Policy Statement 465, which begins as follows: "**The ASCE supports the concept of the master's degree as the First Professional Degree (FPD) for the practice of civil engineering (CE) at the professional level.**" This policy was explicitly supported in *Building ASCE's Future – Strategic Plan* adopted in 2000. The ASCE Board then formed the Task Committee for the First Professional Degree in October 1999 and charged it with "developing a vision of full realization of ASCE Policy Statement 465 …and a strategy for achieving this vision" [8].

The final report of the Task Committee for the First Professional Degree was submitted in August 2001 [8], and it identified the fundamental issue as: ***The current four-year bachelor's degree is becoming inadequate formal academic preparation for the practice of civil engineering at the professional level in the 21st century***.

Policy Statement 465 initially focused on the designation of a master's as the first professional degree for the practice of civil engineering. The Task Committee believed that the focus should be on establishing the prerequisite educational requirements for licensure and practice at the professional level and recommended that Policy Statement 465 be retitled as *Academic Prerequisites for Licensure and Professional Practice* and that the policy be refined to read: "**The American Society of Civil Engineers (ASCE) supports the concept of the Master's Degree or Equivalent (MOE) as a prerequisite for licensure and the practice of civil engineering at the professional level.**"

The Task Committee for the First Professional Degree identified strategies and tactics that would be integral to full realization and implementation of Policy Statement 465. Four major action items, each with supporting tasks, were identified as being necessary for completion over the course of the next 20 years. These action items were supported by a total of 31 specific tasks.

In October 2001, the ASCE Board approved the refined Policy Statement 465 entitled "Academic Prerequisites for Licensure and Professional Practice" with the revised wording. ASCE's Task Committee on Academic Prerequisites for Professional Practice was authorized and charged to develop, organize, and execute a detailed plan for the full implementation of the policy statement.

In October 2004, the policy was revised unanimously by the ASCE Board. The current wording of this policy supports "**the attainment of the Body of Knowledge (BOK) for the entry into the practice of civil engineering at the professional level.**" Undergirding this policy is the belief that the body of knowledge necessary to enter the practice of civil engineering at the professional level in the future will be beyond the scope of a traditional 4-year bachelor's degree plus the required practical experience. The body of knowledge required to support ASCE Policy Statement 465 means the knowledge, skills, and attitudes necessary to be a licensed professional civil engineer [3].

Previously, in November 2003, the ASCE Board authorized the Committee on Academic Prerequisites for Professional Practice (CAP^3) as a successor to the task committee with a mission to develop, organize, and implement ASCE's Policy Statement 465 "Raise the Bar" initiative. By changing the committee from a task committee to a standing committee, the Board explicitly acknowledged that this effort would take many years and require continuous resources.

Parallel to, and independent of, the ASCE engineering education reform activities, the National Academy of Engineering (NAE) was also studying the future education of engineers. The NAE's Committee on Engineering Education originated and chartered a two-phase project. Phase I of the project culminated in a report entitled "The Engineer of 2020 – Visions of Engineering in the New Century" [9]. The Phase II report is entitled "Educating the Engineer of 2020 – Adapting Engineering Education to the New Century" [10]. This NAE study is the subject of the second part of this paper.

The first recommendation of the Phase II report of the NAE Engineer of 2020 study is as follows:

> *"1. The baccalaureate degree should be recognized as the "pre-engineering" degree or "bachelor of arts" in engineering degree, depending on the course content and reflecting the career aspirations of the student."* [10]

The congruence between ASCE's engineering education reform efforts and the NAE study is evident. The other recommendations of the NAE Phase II report are equally supportive of the direction that ASCE has taken.

CAP³ ACTIVITIES

ASCE realized that successful implementation of Policy Statement 465 would necessarily involve other entities besides ASCE. Therefore, the activities of CAP^3 were structured to facilitate communications with these other groups and to promote joint efforts that would ultimately facilitate success in education reform. In other countries, where accreditation and licensure exist, the education, accreditation and licensure functions related to engineering practice are usually combined or closely allied in some manner. However, this is not the case in the United States.

The U.S. universities that offer civil engineering degrees are autonomous, and to a certain extent, they operate in a competitive environment. There is a finite number of college students who choose to study civil engineering and this pool of students must be spread over the 220± accredited civil engineering programs every year. The closest to a civil engineering educational umbrella group is the Civil Engineering Department Heads Council. Representatives of this council have been closely involved in the ASCE activities from the inception of Policy Statement 465 and continue to provide valuable input to CAP^3.

In the United States, the Accreditation Board for Engineering and Technology (ABET) is responsible for accrediting engineering programs. ABET is sponsored by a federation of 28 professional societies, including ASCE. ABET accredits engineering programs through its Engineering Accreditation Commission (EAC), and other technological programs through its other three commissions, (Computing Accreditation Commission, Technology Accreditation Commission, and Applied Science Accreditation Commission).

Professional licensure activities for engineers in the United States are extremely splintered with each of the individual states and territories being responsible for its own professional licensing, resulting in a total of 55 licensing jurisdictions. Each of these is free to establish its own rules and regulations; however, they are encouraged, but not required, to follow the Model Law format developed by the national umbrella group for licensure, the National Council of Examiners for Engineering and Surveying (NCEES).

In spite of the splintering of the licensure process, ASCE has received strong endorsement of the education reform concept from both the National Society of Professional Engineers (NSPE), and the NCEES.

With this short background, the necessity of communicating and cooperating with entities inside and outside of ASCE should be abundantly clear. The mantra of CAP^3 from the beginning has been "communicate-

communicate-communicate." The CAP[3] constituent committees are:

The **Curricula Design Committee** evaluated the Body of Knowledge, mapping it against the curricula of 25 participating undergraduate programs, and making suggestions on inconsistencies and how to improve the BOK. The Curricula Design Committee, in conjunction with the department heads group, is leading the charge to engage civil engineering faculty and administrators.

The **Accreditation Committee** has formulated revised civil engineering program accreditation criteria and submitted these to the Engineering Accreditation Commission of ABET. The goal of this endeavor is to incorporate the requisite body of knowledge into civil engineering curricula via the basic level civil engineering program criteria and the advanced level general criteria.

The **Licensure Committee** provides input to CAP[3] and to the other constituent committees on licensure issues. This committee has closely monitored the activities of the National Council of Examiners of Engineering and Surveying regarding proposed modifications to its Model Law. Additionally, the Licensure Committee continues to identify states that may wish to consider early implementation of additional engineering education requirements as a prerequisite for engineering licensure.

The **BOK Fulfillment and Validation Committee** began work in the fall of 2004 on two fronts. It explored concepts to allow alternative education providers, other than universities, to provide credible post-graduate engineering education. To be viable, such alternative education channels must be equivalent in academic rigor and individual performance assessment to upper level undergraduate and graduate-level education at traditional universities. CAP[3] has recognized the increasing importance of distance learning and private, corporate or government providers of education/training.

The **Levels of Achievement Committee** recommended a system based on the proposed levels of achievement consistent with the six levels of cognitive recognition as described in Bloom's Taxonomy. This committee worked closely with a parallel committee of ABET to identify a process for modifying both the ABET General and Program Accreditation Criteria for all four commissions of ABET also based on Bloom's Taxonomy [4,5].

The sixth constituent committee is the new **Body of Knowledge Second Edition (BOK-2) Committee**. This committee is now completing its work and the report of its work should be available by the time of ICEE 2007, or soon thereafter. The site http://www.asce.org/raisethebar. contains the work products of all of the CAP[3] committees

THE NAE ENGINEER OF 2020 PROJECT

The NAE Engineer of 2020 project was initiated by the Committee on Engineering Education of NAE largely because there was concern by industry that, while the engineers being educated today were very well trained technically, they were not well positioned to adapt to changing global circumstances. There was concern that new graduates lacked a realistic understanding of the critical issues faced in industry (understanding the bottom line, addressing the global aspects of technology, and being able to formulate solutions to problems that are not even known now). And there is the continuing problem of engineers not being well educated in professional skills of communicating, teamwork, appreciating the socio-political implications of their work, etc. Their leadership skills also need bolstering.

The project was organized in two phases. Phase I was to develop a vision for engineering and engineering work in 2020. It was a scenario-based planning process which focused on the kinds of issues that future engineers might have to address. Scenario based planning is used by industries to sensitize leaders to the kinds of problems that they might face; it did not attempt to predict future events, but instead to openly imagine what these future events might be and how engineers would address them. Phase I was not to address engineering education changes needed. Those were reserved for Phase II.

The committee looked at the technological as well as societal, global, and professional contexts of engineering practice and about 40 pages of the report are devoted to these. The committee developed aspirations for the engineer of 2020 which included:

- Improve the image of engineering with
    - a public that appreciates the impact of engineering and sociocultural systems
    - a public that recognizes the union of professionalism, technical knowledge, social and historical awareness and traditions
    - experts well grounded in mathematics and science, but also in humanities, social sciences and economics.
- Embrace creativity, invention and cross-disciplinary fertilization to accommodate new non-engineering fields in science, social science and business.
- Assume leadership positions affecting public policy.
- Welcome underrepresented groups into engineering.
- Focus on sustainable development.
- Create a balance in standard of living for developed and underdeveloped nations alike.
- Be proactive in educating engineers to address technological and societal challenges in the future.

The attributes of the "Engineer of 2020" should include: strong analytical skills, practical ingenuity, creativity, communication, business and management, leadership, high ethical standards, professionalism, dynamism, agility, resilience, flexibility, and above all be lifelong learners. In sum, "He or she will aspire to have the ingenuity of Lillian Gilbreth, the problem-solving capabilities of Gordon Moore, the scientific insight of Albert Einstein, the creativity of Pablo Picasso, the determination of the Wright brothers, the leadership abilities of Bill Gates, the conscience of Eleanor Roosevelt, the vision of Martin Luther King, and the curiosity and wonder of our grandchildren."

Phase II of the study was to examine engineering education, in the broadest context, and ask what it needs to do to enrich the education of engineers who will practice in 2020. The study acknowledged that past interventions had been made, but it was sobered by the fact that these have not resulted in systematic change, but rather only isolated instances of success in individual programs. Moreover, the disconnect between the system of engineering education and the practice of engineering appears to be accelerating. A U.S. national poll of the public indicated that 54 percent believed that scientists have "very great prestige," whereas only 34 percent indicated the same for engineers [12]. And this low level of appreciation for engineers was constant from 1977 to 1998, according to the survey.

A sobering note regarding engineers in leadership is that in the U.S. for those with masters degrees in engineering or science, only about 15 percent are in senior management. However, those B.S. degree engineers with masters in business or some other field were about twice as likely to be in senior management positions [13]. This lack of masters degree holding engineers, whose only education had been in engineering or hard science, progressing to leadership positions was one important concern that stimulated ASCE and NAE to pursue studies of engineering reform. Both studies led to recommendations that more attention be given to the professional skills so essential for success in leadership positions. Figure 3 graphically addresses this issue using data from the U.S. National Science Foundation.

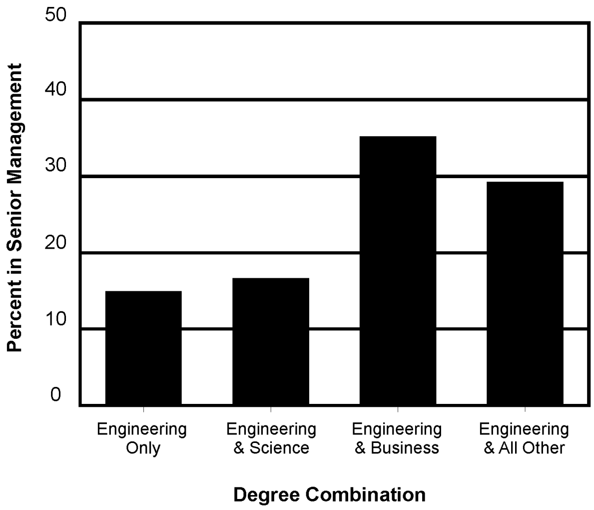

FIGURE 3
LIKLIHOOD OF BEING IN SENIOR MANAGEMENT OF MASTERS' LEVEL ENGINEERING GRADUATES IN THE PRIVATE SECTOR, BY DEGREE COMBINATION. NOTE: MASTERS DEGREES MAY BE IN ANY FIELD, ANY DEGREE COMBINATIONS IMPLY NEITHER ORDER OF DEGREE FIELDS NOR NUMBER OF DEGREES EARNED. IN THIS FIGURE, SOCIAL SCIENCES ARE INCLUDED IN "OTHER" [13].

While there have been many impressive artifacts developed by engineers, it is not possible to dispel the image that an engineer is nothing but a highly trained tradesman. Yet, both the ABET accreditation criteria, EC2000 [11] and the NAE Phase I report reflect a desire to produce engineers with technical competence as well as a broad array of "professional skills."

The Phase II process was to

- Use Phase I scenario to better appreciate a future that is not predictable
- Answer a key question – how can engineers be better prepared to solve problems that can't be foreseen?
    - An engineering summit was held in 2004.
    - Plenary lectures and invited papers gave useful insights and are included in the report.
    - Following the summit the committee considered all ideas and recommendations.

Change is fast –very fast indeed! For instance,

- 2020 is only 16 years from the summit date. Look back 20 years to the mid 1980s:
    - There was no world wide web.
    - Cell phones and wireless communications were embryonic.
    - The dot-com bubble hadn't inflated, let alone burst.
- There is one simple invariant on predictions [14].
    - They underestimate the rate of technological change.
    - And overestimate the rate of social change.

PHASE II RECOMMENDATIONS

The recommendations of Phase II briefly stated include the following:
1) the B.S. degree should be considered a pre-engineering or "engineer in training" degree;
2) ABET should permit engineering programs at an institution to be accredited at both the B.S. and masters level so the masters can be recognized as the engineering "professional" degree;
3) institutions should take advantage of the flexibility inherent in ABET accreditation criteria in developing curricula, and students should be introduced to the "essence" of engineering early in their undergraduate careers;
4) colleges and universities should endorse research in engineering education as a valued and rewarded activity for engineering faculty and should develop new standards for faculty qualifications;
5) in addition to producing engineers who have been taught the advances in core knowledge and are capable of defining and solving problems in the short term, institutions must teach students how to be lifelong learners;
6) engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies on engineering successes and failures as a learning tool;
7) four-year schools should accept the responsibility of working with local community colleges to achieve valuable articulation agreements with their local two-year engineering programs;
8) institutions should encourage domestic students to obtain M.S. and/or Ph.D. degrees;
9) the engineering education establishment should participate in efforts to improve public understanding of engineering and the technology literacy of the public and efforts to improve math, science and engineering education at the K-12 level;
10) the National Science Foundation should collect or assist collection of data on program approach and student

outcomes for engineering departments/schools so that prospective freshman can better understand the "marketplace" of available baccalaureate programs.

CONCLUSIONS

Throughout the 20th century, there has been a significant discussion regarding engineering education. Conferences have been held, papers presented, and extensive studies conducted. However, very little has been accomplished in the way of significant reform. Engineering is still adhering to the thought that a four-year baccalaureate degree, with about 20% less credit hours, is still as adequate as it was in 1905. The American Society of Civil Engineers, the U.S. National Academy of Engineers and the authors of this paper believe that this preparation in no longer adequate.

The American Society of Civil Engineers has elected to move forward and proceed under the premise that the current four-year bachelor's degree is becoming inadequate formal academic preparation for the practice of civil engineering at the professional level in the 21st century. ASCE has received validation of this premise from the recent studies of the NAE as well as by the endorsements of National Society of Professional Engineers and the National Council of Examiners of Engineers and Surveyors. The NAE study is in close agreement and the Phase II report concludes:

"It is evident that the exploding body of science and engineering knowledge cannot be accommodated within the context of the traditional four-year baccalaureate degree. Technical excellence is "the" essential attribute of engineering graduates, but those graduates should also possess team, communication, ethical reasoning, and societal and global contextual analysis skills as well as understand work strategies. Neglecting development in these arenas and learning disciplinary technical subjects to the exclusion of a selection of humanities, economics, political science, language and/or interdisciplinary technical subjects is not in the best interest of producing engineers able to communicate with the public, able to engage in a global engineering marketplace or trained to be lifelong learners." [14].

ACKNOWLEDGMENT

The studies reported herein involved many forward looking engineers and informed technical strategists committed to improving engineering education. Many of those participating in the studies were outside of academia, often with major corporations. We acknowledge the effort of each of them. We particularly appreciate the continuing commitment of NAE President Bill Wulf, without whose leadership and vision the NAE studies would not have happened. Also, we thank all of the Presidents of ASCE who have kept the dream of improving civil engineering education alive for many years. For more information on the ASCE studies go to http://www.asce.org/raisethebar. For information on the Engineer of 2020 reports go to www.nap.edu and click on National Academy Press, then type in "The Engineer of 2020" and click "Find."

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