Some Methods to Achieve Changes in Delivered Civil Engineering Body of Knowledge

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Abstract

ASCE Policy Statement 465 has lead to an extensive examination of the changes needed in civil engineering academic programs to better prepare graduates for licensure and professional practice over the two decades. Many trends, including rapidly growing Information Technology (IT) resources, globalization, and shifts in social and governmental practices, foretell major changes in the career needs for tomorrow's young civil engineer. The Civil Engineering Department at Colorado State University (CSU) has been defining and implementing changes in the curriculum to respond to needs of today's and future graduates as an ongoing task. The department more recently has worked with the ASCE Body of Knowledge Committee as an example of a civil engineering program in a large public university, and the lead author served on that committee. Relevant activities at CSU are described. Three program features at CSU facilitating the curricular changes needed to achieve consistency with the desired BOK are an undergraduate program including an integrated sequence of eight core courses in which many topics to be developed "across the curriculum" are emphasized, an ongoing planning to integrate IT topics into a combination of new or reorganized required and elective courses, and a recently-implemented practice-oriented Masters of Engineering program.

Introduction

The work of the civil engineer will change dramatically as we move beyond the first few years of the 21st Century. The challenges of world's expanding population and societal expectations, the changing global marketplace, and the growing environmental concerns, when coupled with the rapidly growing Information Technology (IT) resources, lead to the conclusion that civil engineering will grow as a vibrant, needed, and rewarding profession. Another conclusion is that these changes need to lead to changes in the educational programs that prepare their graduates for licensure and professional practice in civil engineering, with the topics to be added considerably in excess over those which can be removed as no longer relevant. The resulting pressure on especially the undergraduate civil engineering curriculum is increasingly obvious. This leads to the following basic questions: "What should we teach civil engineering students?" and "How should the needed educational content be packaged – can all be realistically placed within a four-year undergraduate degree program?"

Educators have long received much advice from alumni and practitioners. Typical comments showing that these "customers" of the educational process seek a continuation of the technical content with more content in breadth areas are comments such as these: "Keep teaching the basics, but send us graduates who can communicate better, who understand the business world, and who know something about finance." "Don't neglect technical subjects, but the most important thing is that your graduates think clearly and exercise good decision making skills." The young civil engineering, by being able to increasingly delegate at least the detailed numerical work of analysis and design to software, is finding that more of their job tasks involve management of resources, communications, and general professional practice issues. Given that strong technical abilities are still needed to correctly chose, utilize, and check the output of software, what topics need to be added beyond the "standard engineering" topics? When and how should be taught to students?

Professional Organization Actions Addressing Change

The "Engineering Criteria 2000" accreditation requirements of EAC-ABET (Accreditation Board for Engineering and Technology, Engineering Accreditation Commission)[1] provides some answers to these questions. "Engineering Criteria 2000" specifies a number of outcomes that engineering undergraduate are to develop and demonstrate by the time of graduation. Several among this list of 11 outcomes (perhaps best know as outcomes "a through k") address topics not entirely technical, including (d) an ability to function on multi-disciplinary teams, (f) an understanding of professional and ethical responsibility, (g) an ability to communicate effectively, (h) the broad education necessary to understand the impact of engineering solutions in a global and societal context, (i) a recognition of the need for, and an ability to engage in, life-long learning, and (j) a knowledge of contemporary issues.

The actions of ASCE (American Society of Civil Engineers) regarding civil engineering education are expected to have a great influence in the defining tomorrow's educational requirements. In October 1998, the ASCE Board of Direction adopted the first version of Policy Statement 465 stating[2] "The ASCE supports the concept of the master's degree as the First Professional Degree (FPD) for the practice of civil engineering at the professional level." In October 2001, a modified, re-titled Policy Statement 465[3] was adopted which states "….. the master's degree or equivalent (MOE) as a prerequisite for licensure and the practice of civil engineering at the professional level".

As a step toward implementation, the committees appointed within ASCE following the Policy 465 adoption was the Body of Knowledge (BOK) Committee, charged with describing the BOK which should be taught to and learned by future civil engineering students, with some attention to the issues of how this should be done and who should be the knowledge provider. Colorado State University was chosen to work with the BOK Committee to help define the challenges in developing undergraduate/graduate curricula compatible with the desired BOK within the environment of a large public university including a Ph.D.-level program. The first author became a member of the BOK Committee. The recently-released report of this committee[4] presents and discusses the following four outcomes the committee added to the 11 outcomes of the ABET Accreditation Criteria, the first describing the usual role of the master's degree and the last three addressing profession practice topics:

12. An ability to apply knowledge in a specialized area related to civil engineering,
13. An understanding of the elements of project management, construction, and asset management,
14. An understanding of business and public policy and administration fundamentals, and
15. An understanding of the role of the leader and leadership principles and attitudes.

The report does not allocate these outcomes between the undergraduate and graduate programs, makes a case for the accreditation of master's level programs, and notes that these outcomes generally should be developed at a higher level along the proficiency hierarchy of recognition, understanding, and ability as the student progresses.

After an examination of some of the pressures of change and some of the attributes that often differentiate civil engineering practice from most other engineering, this paper presents several means by which the BOK requirements can be addressed within the academic environment at Colorado State University.

Pressures for Change and Attributes of Civil Engineering Practice

The millennium we have just started will bring many large-scale challenges to the engineering community, ranging from increasing limits on today's energy sources, a growing and older population, a possible rise in ocean levels, and increasing societal expectations within changing governmental systems, to future challenges not yet readily apparent to us. These challenges will be accompanied by changing technological, economic and social developments, the most dramatic likely resulting from information and communications technologies.

The following are among the general classes of changes and their implications for the civil engineering community. These are trends which civil engineering educators need to consider in course and curriculum design:

1. **Globalization** – a global economy, instant communication, cultural integration, immigration and less tie of many jobs to specific locations – which will lead to dramatic changes in civil engineering careers, businesses, and markets.
2. **Population and development patterns** – population increases, an aging population, demand for consumption and standard of living, sustainable development, and quality-of-life and environmental issues – leading to a large quantity of CE work in infrastructure improvement, environmental management, and resource management and allocation.
3. **Rapid Technology and Knowledge Grow** – technology acceleration, knowledge advancement, easy distribution and availability of knowledge, green technologies – all requiring the CE to adapt to new technologies and modes of work.
4. **Government and Regulatory** – triumph of democracy, role of capitalism, privatization, public-private and other partnerships, regulatory environment – leading to changes in how the CE industry interacts with perhaps their largest type of client.

5. **Social shifts** --- equity and poverty issues, multi-culturalism, internationalization, public health, social tensions – leading to more opportunities for civil engineers to respond to social needs, along with more challenges to develop designs and management plans that simultaneously meet human needs and satisfy their public and private clients.
6. **Business** --- increasing speed of business, e-commerce, internationalization of business, mergers and acquisitions, life cycle products – requiring engineers to be flexible and able to learn and respond to rapid business trends and changes.
7. **Work Environment** ---- teams – local and international, complex projects, end of "8-to-5", work anyplace, job and retirement portability – with the dramatic changes in the workplace, individual professionals and engineering firms will not be "entitled" to any particular market, but must show their ability to deliver superior products and services.

Civil engineers will continue to function in their two primary roles—building and managing infrastructure and sustaining environmental resources. For the future civil engineer, preparing for and carving out meaningful careers in these arenas while adapting to change will be a rewarding and exciting challenge.

The initiation of a call for more and better educational preparation of the future engineer by ASCE leads to the question of how the civil engineering differs from other engineering disciplines that may see this need as less critical. Because the civil engineer seldom works with mass-produced final products, rather with those tied to a specific location, civil engineers are closer those most others to the purchasers, users, and observers of their work. These ways in which typical civil engineering work is different from that of other engineering disciplines include:

- It involves more public sector spending and regulation than other engineering groups.
- It involves private practice more than other engineering disciplines and attracts more interest in professionalism.
- It has more influence on the construction and infrastructure industries and on environmental regulation than other engineering disciplines.
- It has a larger social component than other engineering disciplines.
- It is more stable than other engineering disciplines and the size of the occupational group is not increasing rapidly.

Given these trends and characteristics, what knowledge, skills, and abilities must civil engineering students obtain in the college-years to succeed in the 21st Century? Civil engineers will continue to work on infrastructure and environmental problems that are found in both public and private arenas of practice, their work place will continue to include consulting firms, state and local government, federal government, construction, environmental organizations, and other organizations. The civil engineer will have one or more of several different roles—project planner and advocate, regulator, analyst and designer, and builder. He or she might be a specialist in structures, hydraulics, environmental engineering, transportation, geotechnical, or other fields and might work as an entry level designer, a construction manager, a chief executive officer, or in any of many other roles.

General CE Curricula Features at Colorado State

In many ways, the undergraduate civil engineering program at Colorado State University includes a fairly typical, broad-based undergraduate program requiring one or more basic courses in most of the major technical areas of civil engineering. However, our overall educational programs include several features that have facilitated inclusion of some coverage of the last three educational outcome added by the ASCE BOK Committee and which could help accommodate future changes in the topics of these outcomes when the “what, how, and when” decisions are reached by the faculty working with curriculum design.

Some notable characteristics of our undergraduate program environment that differ from the norm include (1) a sequence of eight 3-credit courses, one per semester, which are organized and planned as an integrated sequence addressing many broad topics which need to be developed across the curriculum, topics such as computer tools, design and project planning and management, technical communications, ethics, civil engineering heritage, applications of statistics, etc., (2) the recent introduction of a Soil and Water Concentration, largely to replace a previous degree program in Bioresource and Agricultural Engineering which emphasized water resource and environmental concerns, and (3) the future curriculum changes expected to result from a NSF Educational Planning project conducted by the authors on the topic of “Information Technology in the Civil Engineering Curriculum”[5].

The graduate programs offered by the Civil Engineering Department include a fairly recently introduced practice-oriented Masters of Engineering degree in Civil Engineering. The engineering programs at CSU have long been involved in video-based graduate instruction, this dating back to the late 1960’s. Although a combination of pragmatic conditions and university organizational features at present has resulted in this distance education program being now small in civil engineering, faculty of the CE Department are currently developing selected graduate courses to support a web-based Master of Engineering (Civil Engineering) with a Water Resources emphasis.

The CSU Integrated Civil Engineering Curriculum

After several years of planning and several decades of experience with our two-semester first year civil engineering basic courses and with senior design, we began implementation of an 8-semester sequence of integrated civil engineering courses over a three year transition period starting in 1995. The background of this integrated course sequence, along with other associated changes in the BSCE curriculum, is given in a 1996 paper by Grigg, Criswell, and Siller[6] and a recent update paper[7] This process involved considerable repackaging of present content within a framework allowing much more integration among courses, with one intent being to provide coverage of many important but often ill-defined and under-recognized (within the conventional CE curricula) topics “across the curriculum”. These “across the curriculum” topics include computing skills, design concepts, project organization and management topics, technical communications, applications of statistics and risk concepts, civil engineering history, and professional issues, including ethics.

Each semester also has a theme, varying from basic personal computer tools, surveying, and introduction to design in the first year; infrastructure systems and materials in the second; applied statistics, optimization, and systems modeling in the third, and integrated design and management/professional topics in the senior year. The credit hours for this core sequence largely resulted from a repackaging and reorganization, along with a critical examination of how the "across the curriculum" general topics could be introduced with efficiency. To form the start of the core course sequence, the two first-year courses containing basic computing and drafting skills, introduction to the profession, an introduction to surveying, and basic group-based design projects were reorganized and renamed. The credit hours from an 3-credit senior design sequence (two semesters, 1 + 2 credits) were combined with a class in engineering planning and management to form the last two courses. Hours for the middle four courses came primarily from courses with much or most of their content retained in the core sequence, namely, courses in engineering statistics (3 cr.), in transportation (3 cr.), and a 2-credit laboratory-oriented CE Materials course.

The current content of courses in the integrated CE Core sequence, along with their present quite generic names, follows. The content of each class is constantly under review and changes are fairly common as we better identify opportunities and understand restraints.

CE108– Civil Engineering Principles I: The civil engineering profession, formulation of engineering problems, general computing, network use, equation solvers, professional presentations, basic surveying, group dynamics and project planning.

CE 109 – Civil Engineering Principles II: Civil engineering problem solving and design approaches, introduction to GPS, graphics and more computing skills (Autocad, spreadsheets, applications), introduction to programming (Visual Basic), reports and presentations, groups design.

CE 208 – Civil Engineering Analysis I: Theory and use of measurements, introduction to GIS, surveying data use and management, including mapping and zoning; infrastructure systems and project basics, including layout, costs and cost estimates, codes and standards, risk analysis and topics in statistics;quality in the constructed projects, life-cycle cost concepts, AutoCad and graphical presentations.

CE 209 – Civil Engineering Analysis II: Behavior and properties of construction materials, material standards, instrumentation and use of testing equipment; selection of materials, concrete mix design, use of statistical concepts to help set design values and for quality control practices, failure modes of materials and structures as a result of various types of design errors, technical reports.

CE 308 – Civil Engineering Synthesis I: Modeling, simulating and optimizing techniques for CE systems; statistical tools and concepts for CE risk analysis, time series analysis and numerical modeling; systems behavior (traffic flow, water supply systems, other), performance metrics and sensitivity analysis, project management, communications and presentation skills, ethics.

CE 309 – Civil Engineering Synthesis II: CE infrastructures systems, numerical and decision analysis techniques, statistical and risk analyses, project management, synthesis tools, multi-criterion decision analysis.

CE 408 – Civil Engineering Design I: Design of civil engineering systems; social, environmental, economic and other non-technical design considerations, engineering economics, project organization and management, design project development and operation of design teams, including formal presentations; management of firms, construction industry trends.

CE 409 – Civil Engineering Design II: Group design projects of civil engineering systems, engineering business and management concepts; professional issues, including ethics, registration, and continual learning; formal written project reports and project presentations.

The CE core sequence is a logical home for the introduction of pedagogy techniques and content changes, including those related to IT. This is the basis for our NSF Planning Grant being closely tied to our integrated civil engineering curriculum and its core sequence. The core courses can accommodate the basic IT skills and IT topics that are not limited to a single or a few traditional classes. This is also facilitated by the coordination and dialogue among the CE faculty, including instructors of the core classes, that are most involved in the overall undergraduate program.

Steps in planning changes within the core which elate to IT and/or the BOK topics and their implementation involves defining what is to be added and in what form, then determining how these changes are to be facilitated; including where and how these changes can be fit in. The determination of how to fit in additional content raises the related and often difficult question of what may need to be displaced, reduced, or eliminated. Note that one task of our CE core sequence is to support the rest of the CE curriculum by providing its students with knowledge and skills in several general areas, including IT, so they are available for use elsewhere.

The core course organization has proved quite successful in overcoming two common obstacles to significant program change, namely, (1) having to make changes via individual specialty classes in the traditional less-integrated course approach, and (2) needing to identify, convince, and motivate the individual faculty in change of these individual courses to make such changes in "their" course. The core courses and the critical mass of faculty involved with their detailed planning and assessment can effectively and quickly identify and implement significant changes. Much of the content of the core sequence in the topics of professional and project management and design principles is presented in a book motivated largely by the activities of the authors in this core curriculum sequence[8].

The CE core sequence is not without its challenges, including those related to transfer students, selection and recognition of instructors, faculty capabilities in many "general" areas, a paucity of texts (unless custom text and/or a suite of texts each used several semesters is employed), scheduling of labs, and an earlier and sometimes still lingering perception by some students that these courses may be less "rigorous" than others, especially during the first two years where they sometimes tend to judge courses with well described theories, set equations, and homework with set answers as the more engineering, rather than "softer", topics.

Modifications to Incorporate More Coverage of IT Topics as Applied to CE

The NSF educational planning grant project[5] noted above included a Workshop held in April 2003 which involved participants from the civil engineering profession and other universities. This workshop followed several discussion sessions with civil engineers practicing in several roles in Colorado, varying from recent graduates to consulting firm owners and from sole ownership to large corporation to government at various levels. These and other activities of the project have given us (1) a much better picture of the many applications of IT in designing, operating and monitoring civil engineering works, (2) many contacts with practitioners willing to help bring IT topics to our students, and (3) a better appreciation of the IT skills that the graduates of the next several years should have. Changes in the CE curriculum almost certainly will come through a combination of planned changes across at least several of the core courses, incorporation of IT-topics in specific courses – sometimes at the level of demonstrations to give students familiarity, and by new or reorganized required and elective courses.

Over a decade ago, we worked with out Electrical Engineering Department to create an "Introduction to Electrical Engineering" for engineering students not in EE which replaced the first course in electrical circuits that was previously required for all engineers. This new course includes the basic coverage of circuits to at least the depth expected by the Fundamentals of Engineering Examination, along with other topics such as basic AC and DC power systems, instrumentation, and data acquisition. Planning is starting with EE on possibly revising this course or creating an additional course to include IT components – communication links, sensors, data storage, input/output devices, operation of integrated computing systems – some at the level of ability (the capability to perform or use with competence), others at the level of more abstract understanding or recognition. The formation of a senior-level course, probably an elective, on IT applied to CE Systems (intelligent transportation systems, environmental monitoring, infrastructure assessment and non-destructive evaluation, smart buildings, disaster management and early warning systems, etc.).

Masters of Engineering Programs

The Masters of Engineering in Civil Engineering degree presently offers the following tracks from which the student in the M. Engr. Degree program may select: Water Resources, Environmental, Structural, Geotechnical, and Civil Infrastructure Engineering, with the Water Resources track now accepting students in the web-based Distance Degree Program. This track is a logical selection for the initial track to be offered via Distance Degree because of the long-standing high level of activity, number of faculty, and reputation of the Civil Engineering Department in the area of Water Resources. Within the required 30 credits (usually 10 courses) of class work in the M. Engr. Program, each track includes 3 required core courses, four designated electives from a longer list of courses related to the track topic, and three more open electives. The M. Engr. Program is designed for the student seeking to practice at a technical level not practical with only a BSCE degree, does not include a final exam or individual faculty academic committee, does not entail a research component, and requires the student to have an undergraduate degree in engineering. MS and PhD graduate programs are also available.

The combination of BSCE and M. Engr. is quite consistent with the basic BS + MS model in the BOK Committee report. The three more open electives allows the student some opportunity to explore the less specialized graduate courses, such as an available course in Infrastructure Engineering, and courses more addressing management and project management issues. The M. Engr. Framework offers the potential to more specifically address the last three outcomes added in the BOK Report, including through future courses tailored to more directly address these professional issues. Along this line, some preliminary discussions with the Construction Management program (housed in another College) have taken place on the two programs exploring together the potential of working with the College of Business in creating one or more graduate-level survey-type courses in accounting, management, or other topics of importance to both the civil engineering and construction management graduate student.

Concluding Remarks

Career success comes from many factors—background, education, experience, motivation, and good luck. As engineering educators, we work with an important component in that recipe for success. ASCE Policy 465 and the subsequent Body of Knowledge Committee activities state that the educational preparation of the future civil engineer seeking licensure and significant profession practice no longer can be accomplished within the typical four-year undergraduate program, even when accompanied by the engineering intern experience now required for licensure. Those of us in civil engineering education are consequently challenged to examine the packaging and content of the civil engineering degree programs we offer, as Policy 465 and the BOK learning outcomes are very significant inputs from our professional community.

Properly responding to changing needs requires several steps. First, the needs must be identified and evaluated relative to their immediate and longer term importance. Then a proper response needs to be formulated, which must be planned to be possible within the framework of the resources available (faculty, financial, facilities, etc.) and limitations. Implementation and refinement bring their own challenges. Although some of the methods described in this paper are facilitated by specific characteristics of the academic programs at Colorado State, most are quite transportable to other environments. With the encouragement and challenges given by the ASCE Policy 465 and subsequent professional committee output, including that from committees that will follow the BOK Committee, graduate programs along the line of the Masters of Engineering are expected to be more common. Just as the role and functions of tomorrow's civil engineering will differ from the "traditional engineer" image which still is common, tomorrow's educational program also must be significantly different from what is now described in our academic catalogs, now generally available on the web. Those of us in civil engineering education should look forward with enthusiasm to the important task and professional excitement of participating in continually working toward defining and delivering the best possible educational program for those who will work to provide the infrastructure systems and environmental quality needed to provide an increasing quality-of-life for citizens of the world throughout at least the present 21st Century.

References

1. ABET. (1999). Engineering Criteria 2000, Criteria for Accrediting Engineering Programs during the 1999-2000 Accreditation Cycle. www.abet.org.
2. ASCE Board of Direction, "Policy Statement 465 – First Professional Degree", ASCE, October 1998.
3. ASCE Board of Direction, "Policy Statement 465 (revised) – Academic Prerequisites for Licensure and Professional Practice", ASCE, October 2001.
4. Body of Knowledge Committee of the Committee on Academic Prerequisites for Professional Practice, "Civil Engineering Body of Knowledge for the 21st Century – Preparing the Civil Engineering for the Future", ASCE, January 2003. www.asce.org/raisethebar
5. Grigg, N., Criswell, M. E., Fontane, D. G., and Siller, T. J., "Information Technology in the Civil Engineering Curriculum", accepted for publication in ASCE Journal of Professional Issues in Engineering Education and Practice.
6. Grigg, N., Criswell, M. E., and Siller T. J., "Integrated Civil Engineering Curriculum: Implementation and Management", Journal of Professional Issures in Engineering Education and Practice, Vol. 122, No. 4, 1996, pp. 167-171.
7. Grigg, N. S., M. E. Criswell, D. G. Fontane, L. Saito, T. J. Siller, and D. G. Sunada. "Integrated Civil Engineering Curriculum: Five Year Review", accepted for publication in ASCE Journal of Professional Issues in Engineering Education and Practice.
8. Grigg, N., Criswell, M. E., Fontane, D. G., and Siller, T. J., Civil Engineering in the 21st Century, ASCE Press, American Society of Civil Engineers, 2001.

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