Session 2315

Suggested Topics for a Civil Engineering Curriculum

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Abstract

As continued developments in computer hardware and software provide us with more efficient means to carry out cumbersome computations and with enhanced means of communication and information transfer, the role of civil engineers must change. The current civil engineering curricula at most universities are no longer appropriate to produce leaders of our society in the 21st century. If engineers want to maintain a prominent position in society a new curriculum that properly balances mathematics, natural sciences and engineering with humanities and social and political sciences must be developed and implemented. This new undergraduate curriculum should provide students with a basic knowledge of the following topics: (1) Mathematics, basic and engineering sciences; (2) Broad-based technical aspects of civil engineering; (3) Principles of uncertainty and risk analysis; (4) Decision analysis and business principles; (4) Management principles; (5) Societal needs, ethics, public policy, and political science; and (6) Communication and leadership skills. These topics should be taught in an integrated manner, and reinforced throughout the curriculum repeating their applications in various classes. In addition, the students should be exposed to (1) engineering practice through a variety of means including summer internships, cooperative programs, and interactions with practicing professional engineers; and (2) different cultures and international projects. Faculty members need also to be continuously exposed to practical problems in order to bring back that experience into the classroom. New faculty members should have practical experience or be provided with means to acquire it. To do so, it is necessary to change the faculty reward system by emphasizing the quality instead of the quantity of faculty work. In this paper, we discuss these various aspects in some detail.

I. Introduction

Since the fifties the emphasis in engineering education has been on mathematics, basic science and theoretical engineering courses at the expense of more practical engineering offerings and liberal arts. Engineering students and faculty have often treated humanities and social science courses as necessary evils when in fact these courses were designed and intended to: (1) broaden the engineers' understanding of the societal needs and relationships, and (2) provide a balanced education rather than simple training.

Consequently, many engineering students fail to understand the interrelationships between society and technology. The present civil engineering curricula are not likely to produce leaders of our society. Instead, the current curricula tend to produce academic researchers and/or analysts who can only make advanced computations.

The successful practicing civil engineer of the 21st century is much more likely to be a manager, supervisor or coordinator than a mere detail analyst. Industry, government and academia have all made apparent the need for engineers who have not only in-depth knowledge of physics, mathematics, advanced analysis procedures and specific technical subjects, but who can also communicate effectively, participate in team work with a variety of other professionals, lead interdisciplinary projects, and have an understanding of the legal, political and socio-economic impacts of engineering projects. Many committees and workshops organized with the sponsorship of the National Academy of Engineering, the National Science Foundation, professional associations, and academic institutions have resulted in essentially the same recommendations. As an example, the Engineering Deans Council and Corporate Roundtable (ASEE, 1994) recommended that universities continue to teach scientific and engineering fundamentals as well as a broadened curriculum by incorporating team skills, communication skills, leadership skills, system perspective and integration of knowledge throughout the curriculum with a commitment to quality and ethics.

In this paper, we review several topics for a new curriculum. Many of these topics were presented at a special meeting of the American Public Works Association (APWA) in Louisville, KY in September 2000 (Yao and Roësset, 2001), in the context of public works and infrastructure management. We believe that a four-year bachelor degree in civil engineering followed by a master degree with practical experience is needed for successful civil engineering practice at the professional level. One should thus consider jointly the offerings at the bachelor and Master's level instead of looking at them independently. If we believe that curriculum changes are needed (and not everybody seems to agree with this premise in spite of the overwhelming amount of recommendations in this respect), it would be important for educators to reach some consensus on what the general topics for an appropriate curriculum should be. Once this consensus is reached a more detailed curriculum can be developed and implemented. The development of a new curriculum must be done, however, in an integrated, coordinated, way rather than as a piecemeal adjustment of existing courses.

II. Mathematics and Sciences

All engineering disciplines are founded on mathematics and physical sciences form the foundation of most engineering disciplines (chemical and environmental engineering depend more on chemistry than on physics). The basic mathematics and science courses have been traditionally taken in the freshman year with more advanced material and other science offerings in the sophomore year and several possible electives in the junior and senior years. These courses must be maintained in any curriculum. We should also have an increased coverage of discrete (or applied) mathematics, which have become particularly important with the increased availability and importance of computers. One must finally make sure that the material learnt in these basic subjects is applied in subsequent engineering courses. It is not uncommon today for example to have students learn differential equations in their freshman or sophomore year but never use them until graduate school. Engineering courses often avoid the more rigorous treatment of problems using differential equations under the assumption that these make the subject more difficult and complicated. As a result students not only forget what they learnt in the Calculus courses but they tend to think that it was unnecessary material required only for the sake of requirements. This is an important consideration that applies equally to a number of other topics as discussed later.

Engineering science courses including solid and fluid mechanics, and thermodynamics are typically taught in the sophomore year. As Roësset and Yao (1988) pointed out, engineering mechanics can be used to solve many practical problems in engineering. The actual application of engineering mechanics to real problems should be illustrated through meaningful examples. It was common for engineering students to take all these courses before seeing any actual engineering applications. At present, most students are no longer willing to learn abstract concepts without seeing immediately the purpose and application of what they are learning. As a result, an effort is being made now to incorporate meaningful practical applications as early as possible in the curriculum. However, this effort may be in conflict with another trend to have common courses in engineering sciences for all students as they were in the 1950s. It is our belief that basic science courses should be the same for all engineering and science students. Engineering science offerings should contain specific real applications of interest to each particular discipline (e.g., civil, mechanical, and electrical) while emphasizing the systems approach (e.g., see Bordogna, 1998), and should thus be tailored to the needs of each discipline.

III. Technical Engineering Courses

At present, civil engineering students are often exposed to an introductory course providing an overview of each specialty: environmental, geotechnical, hydraulic, structural, transportation and water resources engineering. Very general presentations tend to be complemented by lectures on use of computers for text editing, drafting or computing, with exposure to many software packages. In some curricula, students are further required to take a basic introductory course in each of these specialty areas. In other curricula, students are not required to take any specific engineering courses beyond the basic engineering science offerings. These students can tailor their programs of study to satisfy their own interests by selecting sequences of courses in a major area and one or two other areas as minors. In that case, the introductory area course should be required of all undergraduate students who have designated that specific area as their major option. The introductory overview course should expose the student to a complete picture of the issues involved within the field. Included in such an introductory course should be (1) actual case studies, and (2) integration of the material of other courses (e.g., mathematics, probability, risk and decision analysis, ecology, socio-economic considerations, communication skills, and political and human factors). This "big picture" should then be followed by more advanced subjects in the same area at the upper division or graduate level.

IV. Principles of Decision under Uncertainty

Engineering involves decision-making with incomplete knowledge. An understanding of decision making, uncertainty concepts and risk analysis is essential for engineers to be able to evaluate alternatives and make rational decisions in the real world. Since the sixties, the departments of civil engineering of many universities have been teaching a required undergraduate course on probabilistic methods. This course is of limited permanent value unless the probabilistic concepts are applied in subsequent engineering courses and properly integrated throughout the curriculum.

In the real world, few things are deterministic without uncertainties. We need to expose students to uncertainty concepts at an early stage. In response to a written question by T. V. Galambos concerning uncertainty in design courses, a panel discussion was held during the 1982 meeting of the North American Fuzzy Information Processing Society (NAFIPS) in Logan, Utah (Yao, 1983). The panelists recommended to

- Teach uncertainty concepts and their applications to freshman engineering students.
- Publish at least one undergraduate textbook with problems and solutions.
- Teach a sophomore course with a general title of uncertainty in which both probability theory and fuzzy sets are covered.
- Teach a senior course in which real data with uncertainty are analyzed.

To date, such courses have not materialized in the States to our knowledge. Recently, Colin Brown, Felix Wong, and Jim Yao (Yao et al. 1999) presented a paper to advocate an undergraduate course in civil engineering to

- Emphasize risk, decision-making, and uncertainty concepts.
- Include other uncertainty analyses such as fuzzy sets (e.g., see Wong, et al. 1999 for civil engineering applications).
- Encourage educators and practitioners to apply non-deterministic methods in their applications.

Based on the personal experience of teaching a civil engineering undergraduate course on probabilistic methods during the past four decades, it will take more than one course (and more than a few instructors) to have practical effects on engineering education. Ideally, uncertainty can be introduced to freshman students in a basic course offered by the mathematics or statistics department or by an engineering department. An engineering course with emphasis on risk analysis and decision-making should follow. Such concepts should be reinforced in subsequent engineering courses at all levels with their application advocated by most instructors.

V. Decision-making, Social and Political Sciences, Management, Business

Once students have a solid knowledge of engineering sciences, decision analysis, probabilistic concepts and risk analysis, they can apply these principles to make rational decisions. This requires consideration not only of technical issues but also of the economic, social and political factors affecting all major engineering works as well as environmental factors and sustainable development (e.g., see Poirot, 1997). The planning of civil engineering projects requires the consideration of the complete economics of the project, integration of the design and construction processes, considerations of financing alternatives, and return on investment or other expected benefits to society. Projects that may not be justifiable at a particular time on the basis of simple economics alone may be desirable because of social and political consequences such as the creation of jobs in a depressed area or providing a public service. Engineers must be aware of all these aspects and must be able to incorporate them in their decision-making and evaluation of alternatives. Management of engineering projects requires all these considerations plus management and administrative skills that are rarely taught to engineers at present.

All engineering students take at least one course on engineering economics covering such basic concepts as present worth, rate of return, and cost-benefit analysis. They should also be exposed to several courses on social and political issues, which do not exist at present. Taking an economics and a political science course is again not sufficient. As in the case of differential equations, probabilities and risk analysis, the material learned in these courses must be applied within the context of actual engineering projects for it to be effective and meaningful. The introductory course in each area is a first step in that direction. Design courses should again cover aspects of a real engineering design project. It is particularly important that all design courses incorporate case studies with real or realistic projects and discussion of all their aspects as well as budget preparation. The case study approach has not been used traditionally in engineering courses, but it is becoming more popular nowadays and should be used more often.

Little (1999) talked about stakeholders including elected officials, public administrators, citizens, the financial community, engineers, architects, planners, and the US defense establishment. In a paper on structural health monitoring, Wong et al. (2001) referred to a value chain with the starting link at the "selection of monitoring systems" and ending at "evaluation of tradeoffs (decision support technology and value to stakeholder)." Wong is a principal in the consulting engineering firm of Weidlinger and Associates, Inc. As a practicing engineer, he understands the value to the stakeholders and the need to use financial considerations to convince them.

VI. Communication and Leadership Skills

Many people do not have the time or patience to read reports carefully, but rely instead on headings, outlined extracts, and attractive visual displays to judge the quality of a proposal. Engineering projects (just as legislation, research proposals or educational initiatives) require appropriate marketing and salesmanship to be approved. The technical quality of a project is not enough by itself. The way the project is presented to the decision-makers, funding authorities or to the public in general is crucial to its acceptance. The engineer in charge of the planning and operation of these projects must be able to communicate effectively, both verbally and in writing, taking advantage of all the tools now available for multimedia presentations. Traditional courses on technical communications involving only technical English (oral or written) have to be supplemented today by more general courses on technical presentations, something which is already being done at a number of universities. Courses on communications must be complemented with material on team working, conflict resolution, and leadership.

VII. Practical Experience

When we both were undergraduate students in the fifties, all our teachers had practical experience in engineering. Since the sixties, an increasing number of professors have started teaching without practicing engineering first and thus lack the much-needed ability to bring real-world applications into the classroom. Worse still, engineering educators are over-relying on computer simulations to such an extent that costly experimental studies have been de-emphasized in engineering education. The students need to be exposed to reality with the following steps:

- Active participation of experienced practitioners in teaching - There have been notable and exemplary cases such as the late Professor Walter P. Moore, Jr., at Texas A&M University and Professor John M. Hanson at North Carolina State University. However, they both had Ph.D. degrees and they both were elected members of the prestigious National Academy of Engineering (NAE). What we need in academia are many more experienced engineers whether they have doctoral degrees and/or are elected members in NAE or not.
- Actual case studies - We need industry to share actual case studies with academia. With the assistance of faculty members, practicing engineers can prepare these case studies for use by students.
- Exposure of faculty members to real engineering problems - Many faculty members need to be exposed to real engineering problems. However, the present faculty reward systems do not recognize such efforts. Many of them pay lip service to such accomplishments, and at most give one-time teaching awards (rather than permanent salary raises) for such efforts.
- Summer internship and/or cooperative program - We need more firms and public works agencies that are willing to sponsor students (and faculty members who lack experience) to obtain practical experience through summer internships and/or cooperative

programs. Following the professional master's programs, we can make the "clinical" experience a required part of the program.

- Re-emphasis of experimental studies - Students should be taught how to conduct good experiments. Results of new analytical studies must be validated by experiments.

The practical experience of faculty members is especially important for this suggested curriculum. We must merge the interests of academicians and practitioners again in order to be successful in our effort to upgrade the profession.

VIII. Length of Education

Even prior to the fifties, there have been discussions about lengthening the period of formal education in engineering. It is vital that the curriculum be reformed as well as that the length of formal education in civil engineering be extended. Since the adoption of a policy statement on a master's degree as the first professional degree by the Board of Direction of the ASCE in October 1998, the pros-and-cons of additional length of education in civil engineering have been debated (e.g., see Yao and Lutes, 1999). The debate continues at present. We believe that it is desirable to produce qualified civil engineers with an additional length of formal education. We can teach the basic mathematics, science, humanities, social science, decision theory, engineering practice, etc. in the limited time available in the undergraduate program, but we cannot cover the more complex topics. For the graduates to make an immediate impact as a civil engineer practicing in water resources, environmental engineering, transportation, or public works and infrastructure management, they need the additional knowledge that can only be covered in the master's degree. Skills in infrastructure management like condition assessment of existing facilities, analysis of needed work on existing facilities, and planning and programming work on existing facilities is well beyond what can be covered in the undergraduate curriculum. Nevertheless, we have to address these legitimate concerns in the new curriculum. For those students who are not interested in studying advanced technical subjects, they may pursue a master's degree in engineering management after the BSCE.

IX. Summary and Conclusions

We believe in summary that a student should have (1) a broad-based undergraduate education in civil engineering; (2) a more specialized master's degree to practice civil engineering at a professional level; (3) exposure to engineering practice through summer internships and/or a cooperative program; and (4) a strong education in mathematics, statistics, basic and engineering sciences, and technical aspects of civil engineering as well as risk analysis, management principles, social and political sciences, ethics, and communication skills.

In today's global economy civil engineering students who become successful professionals are likely to be involved in one or more international projects during their lifetimes. It is therefore important that they learn about other cultures and about engineering as taught and carried out in other countries. Interchange of students among collaborating universities is now common in Europe. American Universities have had for years large numbers of international students and have sent students in humanities to other countries for diverse periods of time. It is rare, however, for US engineering students to study abroad and this is a situation that should be remedied.

Realistic projects should be used as case studies to emphasize these issues and these topics should be taught in integrated courses and reinforced throughout the educational process. It is particularly important that the curriculum consist of logical sequences of coordinated courses rather than an ensemble of independent and loosely related offerings. This requires some amount of faculty time to ensure continuity of the topics in the various courses. Very often a particular instructor is only concerned with the subject he/she teaches and has little knowledge of what is covered in preceding or following subjects. Appropriate coordination is lacking in many instances because individual faculty members are too busy with other activities (such as writing research proposals, supervising research, writing technical papers or doing administrative work) to be able to devote more time to the overall academic program in addition to their own teaching duties. Within the present reward system of most research universities, major curriculum changes and improvements, which involve more faculty time become extremely difficult unless special funds are provided by government agencies for this specific purpose, and then the coordinating efforts may only be conducted while the funding lasts.

To successfully introduce a new curriculum, it is necessary to change current faculty reward systems. Roësset and Yao (2000) would like to measure the quality (in lieu of quantity) of faculty work and reward the faculty accordingly. Recently, Sarin (2000) discussed the ABET EC-2000 criteria in terms of quality assurance. He recommended changing the faculty reward system "or EC-2000 will never achieve its intended purpose."

In this paper, we suggested general topics to be included in a new civil engineering curriculum. After there is a consensus of topics, a detailed curriculum can be developed. While it is important to produce the quantity of civil engineers needed to fill the demand, caution must be taken in attracting qualified students who can think critically. Otherwise, we will produce many more technicians instead of engineers. Meanwhile, we need to pay attention to diversity. Moreover, we must attract students interested in a more active role in management and politics in addition to technical matters.

Some of our friends have expressed pessimism in relation to the implementation of this type of curriculum within a reasonable amount of time. They also question the efficacy of a curriculum change in improving the social status of civil engineers. We agree with them that difficult tasks are ahead if something is to be done. For the sake of future civil engineering practice at a professional level, however, we must try harder and keep trying.

X. Acknowledgement

We wish to thank the Carolyn S. and Tommie E. Lohman '59 Professorship in Engineering Education, and the Wofford Cain '13 Senior Chair of Engineering in Offshore Technology at Texas A&M University for their financial support in preparing and presenting this paper.

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