A Revised Civil Engineering Curriculum

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Abstract

In response to the ABET EC2000 criteria and the need to periodically review and update curricula, the Department of Civil and Environmental Engineering at the University of Missouri-Columbia has recently revised its undergraduate curriculum. While the ABET 2000 criteria do not require a major curriculum revision, they provide an opportunity to leverage the accreditation process to improve our undergraduate education. Also, ABET EC2000 program criteria now dictate that civil engineering programs must demonstrate that graduates have proficiency in a minimum of four major recognized civil engineering areas.

This paper describes the old and new curricula, with a focus on how we expect the changes to improve undergraduate experiences and how we intend to assess the efficacy of the program. Of particular interest to other civil engineering programs is how we intend to develop and assess the proficiency of our students in four major civil engineering areas. As part of the revision process, we informally surveyed several peer institutions to determine what elements of our program were similar and to generate ideas for changes consistent with our institution mission and goals. The paper concludes with our plan for monitoring results and implementing change in the future.

1. Introduction

In response to the Accreditation Board for Engineering and Technology's (ABET) Educational Criteria 2000 (EC2000)[1] and the need to periodically review and update curricula, the Department of Civil and Environmental Engineering (CEE) at the University of Missouri-Columbia (MU) is currently revising its undergraduate curriculum. While the ABET EC 2000 criteria do not necessarily require a major curriculum revision, they provide an opportunity to leverage the accreditation process to improve our undergraduate education. In addition, students and employers expect that curricula will remain current and adjust to meet the needs of the market place.

ABET EC2000 program criteria now dictate that civil engineering programs must demonstrate that graduates have proficiency in a minimum of four major recognized civil engineering areas. Each civil engineering department will have to decide which four (or more) areas are most appropriate for students from that department. This will most likely be based on faculty expertise and major employers of graduates. More challenging, however, is how the departments will demonstrate that students have developed the proficiency. In other words, choosing the areas is easy, but proving that graduates are proficient is not.

The University of Missouri-Columbia is a land-grant university with a mission to serve the state of Missouri. The three components, then, of the university's mission are research, education, and service/outreach. Civil Engineering education at MU began in 1856 with the establishment of the first Chair of Civil Engineering, and the Department of Civil Engineering was established soon after in 1859. The Civil Engineering baccalaureate program was first accredited by ABET (formerly EPCD) in 1936. In 1998, the name of the Department of Civil Engineering was changed to the Department of Civil and Environmental Engineering.

As part of our curriculum revision process, we informally surveyed peer institutions to determine what elements of our program were similar and to generate ideas for changes consistent with our institution mission and goals. This paper describes the survey results, and the old curricula and some proposed changes. Of particular interest to other civil engineering programs is how we intend to develop and assess the proficiency of our students in four major civil engineering areas. The paper concludes with our plan for monitoring results and implementing change in the future. It is our hope that this paper will promote further exchange of ideas and sharing among departments across the nation.

2. Current Objectives, Outcomes, and Curriculum for MU Civil Engineering

The MU Civil Engineering program was last visited by ABET in the fall of 1999. The educational objectives and program outcomes in place at that time are current. The educational objectives of the MU Civil Engineering Bachelor of Science program are to prepare students to enter the profession of Civil Engineering, to prepare students for graduate study, and to prepare students to engage in life-long learning. Graduates of the program are proficient through their education to work immediately upon graduation in most areas of the profession including environmental engineering; geotechnical engineering; hydraulics, hydrology, and water resources; structural engineering; and transportation/traffic engineering. Specifically, the graduates will have:

1. an ability to apply knowledge of mathematics and science,
2. an ability to collect, analyze and interpret data,
3. an ability to design a system, component or process to meet desired needs,
4. an ability to function on teams,
5. an ability to identify, formulate and solve civil engineering problems using techniques, skills and modern tools necessary for civil engineering practice,
6. an understanding of professional and ethical responsibility, particularly the ASCE code of ethic's fundamental principles and canons,
7. an ability to effectively communicate, and
8. breadth and depth in their general education as well as their technical education.

The engineering topics in the curriculum are selected to provide the necessary technical abilities and skills to meet the departmental educational objectives. Theses topics start with basic computer and graphics courses and a freshman design experience. These are followed with basic engineering science courses that ground the students in fundamentals necessary for future coursework and a sophomore design experience. Engineering topics courses in the junior year provide students with the basic fundamentals in the areas of environmental engineering;

geotechnical engineering; hydraulics, hydrology, and water resources; structural engineering; and transportation/traffic engineering. Many of the junior level topics courses contain elements of civil engineering design. Elective courses in the senior year enable students to specialize in one or more areas of the program or to obtain a broad educational background across the civil engineering discipline.

Design is integrated throughout the curriculum starting with a freshman design course (Civil Engineering Design I), followed by a sophomore design course (Civil Engineering Design II). Design components are contained in most required engineering topics courses. These include Soil Mechanics, Reinforced Concrete Design or Structural Steel Design, Hydrology, Applied Fluid Mechanics, Water and Wastewater Treatment, and Transportation Systems Engineering. Design also is included in many of the elective courses. The design experience culminates in a major senior capstone design experience, Civil Engineering Systems Design. The capstone design project is supplied by consultants, governmental agencies, etc. and is a project they have worked on or are working on currently. The capstone course is a "real-life" design experience that draws upon most prior course knowledge. The course involves working in teams; both oral and written presentations; a final design report; and oversight, interaction and evaluation by practicing engineers from industry and government organizations.

The existing curriculum in CEE has evolved over the years, with the last major revision completed in about 1995. That revision was also driven by ABET criteria, and was focused on integrating design throughout the curriculum, improving communication skills, and developing professional skills (projects, teams, and ethics). Since then, the faculty has made minor changes on an ad-hoc basis.

Requirements of the curriculum can be divided into four categories: Math & Basic Science, General Engineering Topics, Civil Engineering Topics, and General Education. Table 4 shows the titles of the required courses and the number of required and elective credit hours in each of these areas. MU general education requirements dictate that students take an American history or political science class and two "writing-intensive" courses. They must take 9 hours of Social/Behavioral Science electives and 9 hours of Humanities/Fine Arts electives. To meet past ABET requirements, the CEE department also required that students take an economics class and complete a "cluster," a three-course sequence of topically related courses, of which one is beyond the freshman level.

3. Concerns Regarding the Current Curriculum

In 1998, the name of the MU Department of Civil Engineering was changed to the Department of Civil and Environmental Engineering. At that time, it was anticipated that department would develop an environmental option to our Civil Engineering curriculum. It was felt that our current curriculum inhibited the development of an environmental option due to inflexibility in the Math & Basic Science and General Engineering Topics categories within our curriculum.

Table 4. Current MU Civil Engineering Curriculum

Category	Required Courses	Hrs.	Elective Courses	Hrs.	Total Hrs.
Math & Basic Science	Calculus I, II, III Differential Equations University Physics I, II General Chemistry II Subtotal	13 3 10 3 29			29
Engineering Topics - General	Algorithm/Prog. I Engr. Graphics Statics Thermodynamics Mechanics of Materials Electrical Circuits Dynamics Fluid Mechanics Subtotal	3 3 3 3 3 3 3 3 24			24
Engineering Topics - Civil	Civil Design I, II Civil Systems Design Transportation Syst. Engr. Structural Analysis Steel or Conrete Design Civil Engr. Materials Soil Mechanics Hydrology Fluid Mechanics Lab Applied Fluid Mech. Water/Wastewater Treat. Subtotal	6 3 3 4 3 3 3 3 1 2 3 34	CE elective CE elective CE elective CE elective	3 3 3 3 12	46
General Education	Exposition & Argumentation Subtotal	3 3	Social/Behavioral Human./Fine Arts Approved Electives Subtotal	9 9 6 24	27
Total Hrs					126

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Current ABET EC2000 general program criteria[1] prescribe that programs must demonstrate that graduates of the program have:

(a) an ability to apply knowledge of mathematics, science and engineering,
(b) an ability to design and conduct experiments, as well as to analyze and interpret data,
(c) an ability to design of a system, component, or process to meet desired needs,
(d) an ability to function on multi-disciplinary teams,
(e) an ability to identify, formulate, and solve engineering problems,
(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,
(j) a knowledge of contemporary issues, and
(k) an ability to use the techniques, skills, and modern tools necessary for engineering practice.

Additionally, ABET Civil Engineering-specific program criteria prescribe that Civil Engineering programs must demonstrate that graduates of the program have:

(l) proficiency in mathematics through differential equations; probability and statistics; calculus-based physics; and general chemistry,
(m) proficiency in a minimum of four major civil engineering areas,
(n) the ability to conduct laboratory experiments and to critically analyze and interpret data in more than one of the recognized civil engineering areas,
(o) the ability to perform civil engineering design by means of design experiences integrated throughout the professional component of the curriculum, and
(p) an understanding of professional practice issues such as: procurement of work; bidding versus quality based selection processes; how the design professionals and construction professions interact to construct a project; and the importance of professional licensure and continuing education.

A self-evaluation of our current objectives does not indicate that significant changes are necessary. A self-evaluation of our current outcomes indicates that most of our current outcomes (labeled 1-8 above) are very similar to EC2000 general (labeled a-k above) and Civil Engineering program specific (labeled l-p above) outcomes. We are, however, concerned about whether our current curriculum will develop graduates with the abilities/proficiencies prescribed in the ABET EC2000 criteria. Specifically, we are evaluating whether our current general education requirements provide for the broad education necessary to understand the impact of engineering solutions in a global and societal context, and whether they impart knowledge of contemporary issues. Other engineering programs at MU share these concerns, and there are efforts being made at the college level to review current general education requirements in light of these concerns. We are also concerned about how our graduates will demonstrate proficiency in a minimum of four major civil engineering areas.

The ASCE Committee on Curricula and Accreditation[2] has prepared a Draft Commentary to assist Program Evaluators in their task of evaluating Civil Engineering programs for ABET.

This commentary includes a section entitled, "Explanation of the use of the term 'proficiency'." The following list includes paraphrased excerpts from this explanation.

- Proficiency, as defined by academia, generally means satisfactory progress towards the requirements of the degree and graduation.
- ABET program criteria authors have used proficiency to be a measure by the profession of their expectations of the basic Civil Engineering knowledge imparted to the graduate.
- Demonstration of proficiency implies an ability to accomplish something, such as design of a reinforced concrete beam under certain conditions.
- Proficiency differentiates the engineering program from the technology program.
- The graduate of an engineering program needs to be able to apply knowledge to situations that do not have well-defined constraints, and to analyze, quantify, and develop a suitable solution.
- Proficiency implies a depth of capability beyond the introductory level.
- Proficiency increases throughout the educational experience, culminating in the ability to assess and resolve situations that require a depth and breadth of understanding of engineering principles, concepts, procedures, and ethics, as well as economic and social constraints.

It is important to note that none of these paraphrased excerpts alone provides a definition of "proficiency", but rather one must consider them collectively, in order to develop an understanding of what is expected of a graduate deemed to be "proficient" for ABET purposes.

4. Peer Institution Curricula

To determine how other institutions are addressing these curriculum issues, we conducted an informal survey in January 2001. The results are based on information about curriculum requirements available on the web sites of the 27 American Association of Universities (AAU) institutions (Table 1). Some of these schools have already undergone the ABET 2000 review process, while others have not. We were particularly interested in which areas were chosen to satisfy the ABET proficiency requirement and how many credit hours are required in each area. In some cases, the areas were explicitly listed, but in many we had to interpret based on listed faculty expertise and numbers of required credit hours in each area. Table 2 lists the primary areas of emphasis and the number of institutions offering each.

Most institutions have a required introductory course in several areas, but the requirements for upper level courses vary. For instance, at some institutions, most courses are required, and students have very few electives, which ensures that all students get the same broad-based education. Others have fewer required courses but students must distribute their electives among emphasis areas. Still others have very few restrictions on course selection beyond the introductory courses, which allows students a great deal of specialization. This latter approach is more wide open at larger institutions where more courses are offered, and less so at others, where the number of courses available in any one area prevents students from concentrating too heavily.

Table 1. AAU Institutions and their Curriculum Web Sites

Institution	Primary Web Site Used
University of Arizona	http://w3.arizona.edu/~civil/
University of California, Berkeley	http://sis450.berkeley.edu:4500/catalog/gcc_view_req?p_dept_cd=CIV+ENG
University of California, Davis	http://www.engr.ucdavis.edu/college/information/99BULLETIN/cee.htm#curld
University of California, Irvine	http://gram.eng.uci.edu/civil/undergraduate/undergrad_curriculum_civil.html
University of California, Los Angeles	http://www.cee.ucla.edu/ugrad/undergrad.htm#CURRICULUM
University of Colorado at Boulder	http://civil.colorado.edu/web/ugrad/civilw.htm
University of Florida	http://www.ce.ufl.edu/undergraduate/program.htm
University of Illinois at Urbana-Champaign	http://cee.ce.uiuc.edu/Curriculum.asp
University of Iowa	http://www.cee.engineering.uiowa.edu/undergradsmt.htm
Iowa State University	http://www.iastate.edu/~catalog/catalog/curric/eng-civ.htm
University of Kansas	http://civil-env.ce.ukans.edu/
University of Maryland at College Park	http://www.cee.umd.edu/stud/bscivil.html
University of Michigan	http://www.engin.umich.edu/students/2000_01Bulletin.pdf
Michigan State University	http://www.egr.msu.edu/ugs/Depts/Ce/CEcurr.pdf
University of Minnesota, Twin Cities	http://www.ce.umn.edu/ugrad/programs/cemain.htm
University of Missouri-Columbia	http://www.ecn.missouri.edu/academic/civil/index.html
University of Nebraska at Lincoln	http://www.civil.unl.edu/undergraduate/guide/default.asp
Ohio State University	http://www-ceg.eng.ohio-state.edu/html/programs.html#Degrees
Pennsylvania State University	http://www.engr.psu.edu/ce/academic.html
University of Pittsburgh	http://www.engrng.pitt.edu/~civwww/undergrd/index.htm
Purdue University	http://ce.www.ecn.purdue.edu/CE/Undergrad/currentstudents.whtml
Rutgers University	http://www.civeng.rutgers.edu/info/ugradprog.html
State University of New York at Buffalo	http://www.civil.buffalo.edu/Undergrad/manual.html
University of Texas at Austin	http://www.ce.utexas.edu/academic/course.html
University of Virginia	http://www.cs.virginia.edu/~civil/und-grad.html
University of Washington	http://www.ce.washington.edu/students/undergrad_info/undergrad_admission.html#requirements
University of Wisconsin-Madison	http://www.engr.wisc.edu/cee/current/undergrad/curriculum/spring98/ce/

Table 2. Emphasis Areas of AAU Institutions

Emphasis Area	Number of Institutions	% of Institutions
Construction	14	52
Environmental	25	93
Geotechnical	26	96
Hydrology/Hydraulics/Water Resources	22	81
Structural	27	100
Transportation	21	78
Other (e.g. materials, mechanics, geomatics)	6	22

A comparison of curricula based on credit hours required in each area is more problematic, as some institutions operate on quarter or trimester systems, while most operate on semesters. In addition, some programs offer sub-tracks for specialization with different course requirements. However, the average number of credit hours required for each emphasis area is shown in Table 3. For those programs with sub-tracks, the most general sub-track was considered. We regard statics, dynamics, strength of materials, and fluid mechanics as foundation courses for all areas of emphasis, and therefore, they are not included in the number of credit hours for any emphasis area.

Table 3. Average Number of Credits Required per Emphasis Area

Emphasis Area	Average Number of Credits Required
Construction	3.1
Environmental	3.4
Geotechnical	4.1
Hydrology/Hydraulics/Water Resources	4.3
Structural	5.4
Transportation	3.2
Other (e.g. materials, mechanics, geomatics)	3.5

For the institutions surveyed, Structures is the most common area of emphasis. In addition, the number of credit hours required in the structural area is the greatest. Several institutions required 9 or more credit hours in this area. Based on the current curricula of AAU institutions, it appears that faculty members do not anticipate a great increase in required credit hours to demonstrate proficiency in civil engineering topics. A number of institutions required only one, 3-credit course in one or more areas of emphasis. This does not, however, mean that students have only 3-credit hours relevant to the topic, as one can argue that preparatory course and subsequent design courses provide the foundation for and add to the proficiency in each area.

5. Draft Revised Curriculum

Table 5 shows a draft version of a revised curriculum for our department. The following paragraphs discuss the significant changes. It is important to note that we wanted to make these changes without significantly increasing the total credit hours required to earn a degree

The first change is in the Math & Basic Science category. The current curriculum requires a 10-credit hour physics sequence of courses and a single, 3-credit hour chemistry course. The revised curriculum would allow these same courses, but it would also allow a student to select a 9-credit hour chemistry sequence of courses and a single 5-credit hour physics course instead. Another change in this area is to require a 3-credit hour Math & Basic Science elective course. These changes collectively will allow students to tailor their Math & Basic Science to better prepare them for a particular area of Civil Engineering. For example, a student who is interested in Environmental Engineering might elect to take the chemistry sequence and an additional chemistry course as the elective, whereas a student interested in Structural Engineering might take the physics sequence and an additional math course.

The three additional Math & Basic Science credit hours were acquired by reducing the number of General Engineering Topics hours from 24 to 21. In the revised curriculum, there are 18 hours of required courses and 6 hours of electives in this category. Historically, much of the motivation for requiring the 24 hours of General Engineering Topics was to promote student success on the Fundamentals of Engineering (FE) exam. With the new ABET criteria, and the advent of the discipline-specific FE exam, these credit hours can be better spent on improving proficiency in Civil Engineering areas. Consequently, the traditionally required dynamics, electrical circuits, and thermodynamics courses would no longer be required. Students get some instruction in dynamics and thermodynamics in the first Physics course, and they get some instruction in electrical circuits in the second Physics course. Those students who did not take the second physics course would be required to include an electrical circuits or instrumentation course as one of their two General Engineering Topics electives.

The final changes come in the distribution of credit hours for the required Civil Engineering topics courses. We believe that the constituents of the MU Civil Engineering program have come to expect MU graduates to be proficient in five areas: Environmental, Geotechnical, Structural, Transportation, and Water Resources. Therefore, every student would be required to complete a 4-credit hour course in each of these areas. We expect each of these courses to have an experiential learning component and a design component. The experiential learning component would probably be different for different courses. For example, in the Geotechnical Engineering course, it may be laboratory experimentation, whereas in the Structural Engineering course, it may a computational laboratory. In addition to the five, 4-hour required proficiency area courses, students would take a 3-hour materials course, and either a 3-hour steel or concrete design course. Students would expand on this technical base by selecting four, 3-hour Civil Engineering elective courses. The final leg to this three-legged stool lies in the required sequence of design courses (CE Design I, II and CE Systems Design). In CE Design I and II students will be developing their communication skills, teamwork skills, and their understanding of the design process and professional practice. CE Design II, the sophomore level course, will be a co-requisite for the 5 proficiency-building courses. Students will then be able to apply

Table 5. Draft Revised MU Civil Engineering Curriculum

Category	Required Courses	Hrs.	Elective Courses	Hrs.	Total Hrs.
Math & Basic Science	Calculus I, II, III Differential Equations Basic Science Sequence: Univ. Physics I, II or *Chem II, III &* *Organic Chem I* *Physics 175* or Chem 32 Subtotal	13 3 10 *9* *5* or 3 29 or *30*	1 course selected from a list of approved math & basic science courses	3	32 or *33*
Engineering Topics - General	Algorithm/Prog. I Engr. Graphics Statics Mechanics of Materials Fluid Mechanics Subtotal	3 3 3 3 3 18	2 courses from a list of approved engineering topics courses	6	21
Engineering Topics - Civil	Civil Design I, II Civil Systems Design Transportation Syst. Engr. Structural Analysis Steel or Concrete Design Civil Engr. Materials Geotechnical Engr. Water Resources Engr. Environmental Engr. Subtotal	6 3 4 4 3 3 4 4 4 35	CE elective CE elective CE elective CE elective	3 3 3 3 12	47
General Education	Exposition & Argumentation Subtotal	3 3	Social/Behavioral Human./Fine Arts Approved Electives Subtotal	9 9 6 24	27
Total Hrs.					127 or 128

design skills to practical problems applicable to each of these area proficiency courses. Finally, during their last semester, while taking CE Systems Design, students will work in teams on multi-disciplinary design projects. The multi-disciplinary nature of the projects means that skills from most of the proficiency areas would be applied.

6. Expected Impacts and Assessment

We expect that the proposed changes will have a number of positive impacts on our department and on the quality of our undergraduates' experiences. First, as mentioned above, the revisions will allow greater flexibility for students who want to gain non-civil-engineering knowledge about civil engineering topics (e.g., an advanced chemistry course or an operations research course). Second, the revisions will provide all students with a more meaningful experience in each of the five areas of proficiency. The standard of 4-credit hours will enable the addition of laboratory and/or design components for each area.

We are still in the process of developing our methods for assessment of outcomes. Specifically, how do we demonstrate that students are "proficient" in the selected five areas? We anticipate that we will begin requiring that all our students take the Civil Engineering discipline-specific FE exam. This will provide a nationally normed, quantitative measure of the proficiency of our graduates shortly before they graduate. In addition, we intend to survey employers of our graduates on their expectations of our graduates and how well our graduates meet these expectations. We expect to add to and modify our assessment methods over the next several semesters.

7. Conclusion

The ABET EC2000 criteria are sparking change in Civil Engineering curricula across the nation. Issues facing departments include choosing areas of proficiency and demonstrating that graduating students are proficient. It appears that AAU Institutions are addressing the issue of creating and assessing proficiency in a variety of ways. It is clear from the ABET and ASCE commentaries on "proficiency" that measuring the number of credit hours a student accumulates in an area is not sufficient. However, most programs seem to be developing their areas of proficiency through one 3- or 4-credit course in combination with the pre-requisites for those courses.

It is our view that proficiency is developed not through one course, but through the overall undergraduate experience. Students begin by building basic math and science skills as well as teamwork, communication, and problem solving skills. They then apply these skills in their civil engineering "proficiency" courses. In our proposed model, each of these "proficiency courses" will include a demonstration that students are able to design something in that area. Finally, students will pull all of these skills together and demonstrate them in the capstone design course. We expect that as more programs undergo the EC2000 evaluation, they will demonstrate a variety of ways to meet the requirements. Hopefully, programs will share their experiences so that we can improve the education of our undergraduates at universities throughout the nation.

Bibliography
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