An Innovative Infrastructure Curriculum for 21st Century Civil Engineering

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Abstract

A new curriculum has been developed by the Department of Civil and Environmental Engineering at The University of Wisconsin—Platteville (UWP). The revised curriculum creates a focus on infrastructure topics and the built environment. Classes on infrastructure will be added to the curriculum and infrastructure topics will be added to required engineering courses. Students will develop a local infrastructure report card as a service learning activity to increase awareness of the infrastructure. The local infrastructure report card will also serve as an ABET assessment tool. Details on how an infrastructure theme will be infused throughout the curriculum are presented.

Introduction

The importance of the infrastructure to the economic development of the country is well understood by engineers and many political leaders in the U.S. As highlighted by the 2005 American Society for Civil Engineers (ASCE) Infrastructure Report Card[1], the United States' infrastructure is in very poor condition, and was given an overall grade of D. Because of these infrastructure needs, civil engineers of the future will need to be skilled at maintaining and upgrading in-place infrastructure in addition to the current emphasis on creating new infrastructure. Unfortunately, the influence of civil engineers in infrastructure management and planning has been waning in recent years.[2]

To better prepare our students to participate in the planning and management of public works, we (the faculty of the Civil and Environmental Engineering Department at UWP) are revamping our curriculum with the goal of educating "citizen engineers."[3] Citizen engineers will be more in tune with the needs of their communities and of the nation, and will be able to effectively address the technical and non-technical issues related to the infrastructure. To meet this end, we are infusing an infrastructure theme throughout the curriculum. The revised curriculum will include at least one new course (i.e. "Introduction to Infrastructure I"), which will specifically address infrastructure needs and the non-technical issues (such as financing, political process, etc.) that are often crucial to successful engineering projects. However, unlike many implementations of curriculum reform[4], our proposed changes will go well beyond the creation of a class or classes. Infrastructure concepts will be interwoven throughout the remainder of the curriculum to provide students with a better understanding of the challenges to be faced in improving, securing, and maintaining the national infrastructure.

In addition to learning about infrastructure in classes, students will evaluate infrastructure components in local communities using direct observation, producing a "local" infrastructure report card. This service learning activity will provide students with a direct connection to a local community and its needs. Our ultimate goal is to produce citizen engineers that have a better understanding of infrastructure, better familiarity with new technologies[5] that are increasingly used in infrastructure management, and a more holistic understanding of the built environment as compared to the engineers currently graduating from our program.

Background

UWP is a four year comprehensive public university enrolling approximately 5,500 undergraduates in three colleges: Engineering, Mathematics, and Science—1,900 students; Business, Industry, Life Sciences, and Agriculture—1,700 students; Liberal Arts and Education—1,900 students. The engineering programs comprise one of the largest undergraduate-only programs in the United States.

The primary mission of UWP is to provide baccalaureate degree programs that meet educational, cultural and economic development needs of southwestern Wisconsin and the larger region. The university is best known for its engineering programs, which include Civil, Environmental, Mechanical, Industrial, Electrical, Software, and Engineering Physics. There are 240 students in the Civil and Environmental Engineering (CEE) Department, which offers two degrees: Civil Engineering and Environmental Engineering. The program has averaged 61 graduates per year over the past 40 years. The CEE curricula are summarized in the Undergraduate Catalog as programs that "emphasize practical applications of engineering with sufficient theory so that an individual can grow with the future as new materials, methods, and designs develop." The vast majority of graduates enter professional practice. Students who pursue graduate school directly upon graduation are recruited by a number of schools and have been very successful. The department faculty is a relatively young, dedicated, and collegial group that is regarded as exemplary throughout the university in terms of teaching effectiveness and in professional development.

The existing curriculum at UWP is typical of conventional CEE curricula. Students complete basic mathematics, science, and general engineering courses in the first two years followed by civil and environmental engineering courses in the remainder of their studies. The CEE program includes a significant laboratory component and practical design projects in the upper level classes. The program culminates in a capstone design class that is taken in the last semester in school. Projects for this class are often solicited from communities and non-profit organizations, and typically incorporate a service learning component.

In reviewing the existing UWP CEE curriculum for this curriculum development project, it became clear that the curriculum had not changed significantly in over 20 years. To illustrate this, the curricula from the 1985 and 2005 catalogs are shown in Table 1. The course changes are very minor, and the *total revisions* made in 20 years to the UWP CEE curriculum consist of the following: replacing Route Layout with Construction Engineering; replacing Technical Writing with 3-9 more credits of Social Sciences and Humanities; changing Chemistry from 8 to 5 credits; removing the Electric Circuits requirement; and a few name changes or changes in the number of units. Moreover, the courses have been taught in the traditional method of daily lecture and weekly laboratory exercises. Many courses build upon knowledge from prerequisites, but there is no overlying theme that ties the entire curriculum together.

Table 1
Comparison of 1985 and 2005 UWP Curricula for Civil and Environmental Engineering

	1985 Curriculum			2005 Curriculum	
Dept.No.	**Course**	**Credits**	**Dept.No.**	**Course**	**Credits**
CE 212	Computer Applications	2	CEE 2120	Computer Applications	3
CE 213	Statics	3	GE 2130	Statics	3
CE 220	Mechanics of Materials	4	GE 2340	Mechanics of Materials	4
CE 263	Elements of Surveying	3	CEE 2630	Elements of Surveying	3
CE 264	Route Layout	4	CEE 3020	Construction Engineering	3
CE 303	Construction Materials	3	CEE 3030	Construction Materials	3
CE 310	Structural Mechanics	4	CEE 3100	Structural Mechanics	4
CE 315	Reinforced Concrete	3	CEE 3150	Reinforced Concrete	3
CE 330	Fluid Mechanics	3	CEE 330	Fluid Mechanics	4
CE 331	Fluid Mechanics Lab	1			
CE 334	Sanitary Engineering	4	CEE 3340	Environmental Engineering	4
CE 353	Transportation Engineering	3	CEE 3530	Transportation Engineering	3
CE 373	Soil Mechanics	3	CEE 3730	Geotechnical Engineering	3
CE 398	Design Project	3	CEE 4930	Design Project	3
CE 4xx	Technical Electives	11	CEE 4xx	Technical Electives	14
Chem 114	Gen. Chemistry	4	Chem 1450	Chemistry for Engineering	5
Chem 124	Gen. Chemistry	4			
Comm 212	Public Speaking	2	Spch 1010	Public Speaking	2
EE 313	Electric Circuits	3			
Engl 113	Freshman Comp.	3	Engl 1130	Freshman Composition	3
Engl 123	Freshman Comp.	3	Engl 123	Freshman Composition	3
Engl 300	Technical Writing	3			
Geol 313	Engineering Geology	3	Geol 313	Engineering Geology	3
IE 113	Engineering Graphics	3	GE 1320	Engineering Graphics	2
IE 222	Dynamics	2	GE 2220	Dynamics	2
IE 382	Engineering Economy	2	GE 2820	Engineering Economy	2
Math 265	Analytical Geometry & Calculus I	5	Math 2640	Analytical Geometry & Calculus I	4
Math 275	Analytical Geometry & Calculus II	5	Math 2740	Analytical Geometry & Calculus II	4
Math 284	Analytical Geometry & Calculus III	4	Math 2840	Analytical Geometry & Calculus III	4
Math	Differential Equations or Statistics	3	Math 3630	Differential Equations	3
			Math 403	Statistics	3
ME 263	Thermodynamics	3	GE 2630	Thermoscience	3
MinE 103	Engineering Methods	3	GE 1000	Engineering Success Skills	1
			GE 1030	Engineering Projects	1
PE 1xx	Physical Education	1	PE 1000	Fitness Assessment	1
PE 1xx	Physical Education	1	PE 1xxx	Physical Education	1
Phy 251	General Physics I Lab	1	Phys 2510	General Physics I Lab	1
Phys 253	General Physics I	3	Phys 2530	General Physics I	3
Phys 261	General Physics II Lab	1	Phys 2610	General Physics II Lab	1
Phys 264	General Physics II	4	Phys 2640	General Physics II	4
	Social Science and Humanities Electives	15		Social Science and Humanities Electives	21
Total Credits		135	Total Credits		134

Knowledge, Skills, and Attitudes of the Citizen Engineer

Before deciding how the curriculum should be reformed, the entire department faculty brainstormed the attributes of the "ideal engineer" in 2020. While we were aware of the report by the National Academy of Engineering Committee on Engineering Education[6], the premise of the ideal engineer of 2020 helped mainly to focus our thoughts on the future needs of our students.

A brainstorming session was moderated by a practicing Professional Engineer who helped to keep us on track and think in terms of the needs of practicing engineers. The primary result of this brainstorming session was to help the entire department see that technical expertise, although essential, is only one of many attributes found in the ideal engineer. Indeed, the brainstorming session focused less on knowledge than it did on skills, and the primary focus was on the *attitudes* necessary in the ideal engineer. Truly, the ideal engineer will also be a citizen engineer; *i.e.*, able and willing to engage in public policy and appreciative of the sustainability of projects. A summary of the attributes of the ideal engineering that resulted from the brainstorming session follows:

- Ability to communicate orally and in written form in a manner appropriate for the intended audience.
- Understanding of local government operations and decision making– planning, engineering, financing, politics, procurement, education of public, etc.
- Ability to evaluate projects from a holistic perspective – environmental, ethical, aesthetic, political, historical, social impact, technical needs, costs.
- Awareness of sustainability issues of projects.
- Ability to use engineering judgment - evaluation of reasonableness of answers, sense of proportion, common sense.
- Ability to make decisions based on an ethical framework.
- Recognition of the need for innovation and an increased willingness to take calculated risks.

Infrastructure throughout the Curriculum

On the same day that the department faculty brainstormed on the attributes of the ideal engineer of 2020, they also brainstormed about what the ideal curriculum would look like in order to produce that ideal engineer.

Results of the brainstorming session showed that the faculty members were in agreement that in order to produce a citizen engineer, the ideal curriculum must do much more than teach technical competence. In order to go beyond technical competence, non-traditional teaching and learning activities would have to be employed. Examples suggested during the brainstorming session included adding a Civil and Environmental Engineering seminar series, requiring attendance at professional conferences (*e.g.*, local and regional ASCE meetings), requiring attendance at local public meetings, requiring attendance on an engineering related Spring Break Field Trip, etc. However, in meetings following the brainstorming session, the department proposed to focus their efforts on infusing infrastructure across the curriculum.

Currently, the CEE department remains in the planning stage for the new curriculum. The remainder of this paper will describe how the CEE department proposes to infuse the infrastructure theme across the curriculum. Specifically, four main strategies will be used:

- creating a new social sciences course and/or using general education classes to fulfill a "theme" requirement for graduation;
- creating a new class(es) on "Introduction to the Infrastructure";
- ensuring that infrastructure topics are covered in every CEE course; and
- requiring students to write infrastructure report card chapters in various courses.

New Social Sciences Course and General Education Theme

All CEE students are required to take a total of seven Humanities and Social Sciences courses. Students often do not ask their academic advisors (we, the faculty) for direction on which courses to take, and often select courses based on reputation for work load (or lack thereof) or how well it fits into their schedule. Not surprisingly, considering their attitude, many students do not gain the full benefit from these courses, and teaching the courses can be tiresome given the attitude of the students enrolled.

The CEE faculty approached the Department of Social Sciences about the possibility of offering a new course that would expand on an existing course, "State and Local Government." We feel that a targeted course in the Social Sciences would be well received by the students, and the Social Sciences faculty members that we met with responded in an extremely enthusiastic way. Preliminary conversations have suggested that the course could cover funding issues, the fundamentals of community planning, as well as the relationship between the quality and availability of the infrastructure and economic development.

Another suggestion was that the civil engineering graduation requirements be modified so that students would use their general education classes to pursue a "theme." For example, students could graduate with a theme in government by taking several general education courses on government and public policy. Other suggested themes were:

- Ethics
- Business Management
- Geography
- International Studies
- Engineering History

The goal of the theme requirement would be to help students develop an area of competency useful to them in their future careers as citizen engineers. This theme requirement was inspired by the curriculum Threads™ requirements employed by the College of Computing at the Georgia Institute of Technology.[7]

New Infrastructure Course(s)

One goal of the revised curriculum is to create a new course (or series of courses) that introduces students to the infrastructure. The goals of the Introduction to Infrastructure class(es) and associated topics are shown below.

- Introduce students to civil engineering (including the history of civil engineering, the role of the civil engineer in society, and the concept of the infrastructure).
    - Field trips
    - Lab experiences
    - Field experiences
    - Historical case studies
    - Infrastructure report card
    - Financing of public projects
    - Applications
        - pavement design
        - pavement analysis
        - concrete mix design
        - solid waste
        - bridge structure evaluation
        - retaining wall evaluation
        - slope stability
        - transportation system analysis
        - water distribution systems
        - wastewater collection systems
        - stormwater conveyance systems
        - drinking water treatment
        - wastewater treatment
- Provide students with <u>skills</u> to become citizen engineers
    - AutoCAD Civil 3D applications
    - Ethical decision-making framework
    - Create and interpret a simple plan set
    - GIS web-based applications
    - Oral presentations
    - Written reports
    - Enhance critical thinking skills
    - Business etiquette
    - Teamwork
- Provide students with <u>knowledge</u> required of citizen engineers
    - Code of ethics
    - Licensure

        - Contemporary issues
- Encourage <u>attitudes</u> found in citizen engineers
    - Understanding of the uncertainty and limitations of empirical models
    - Appreciation of open-ended problems
    - Awareness of infrastructure *systems* (transportation, energy, water, wastewater, stormwater, dams and rivers, communications, ecosystem)
    - Encourage a holistic viewpoint.
        - World population trends
        - Population modeling
        - Public meetings attendance
        - Service learning
    - Appreciate the global and societal impacts of civil engineering projects

Infrastructure in Every Course

The attributes of the ideal engineer of 2020 obtained through the brainstorming session served as the basis for the proposed curricular reform. The department strongly feels, as a whole, that transferring the knowledge and skills and instilling the appropriate attitudes cannot be achieved in a single course, and that it would be a disservice to the students to "save" this knowledge, skills, and attitudes until they were juniors or seniors. Thus, in addition to creating a new infrastructure course(s) to be offered beginning in freshmen/sophomore year, the knowledge, skills, and attitudes must be presented in *every* civil and environmental engineering course.

To ensure that the knowledge, skills, and attitudes required of citizen engineers are integrated throughout the curriculum, a matrix was created. In this matrix, a column would be provided for each course in the curriculum, and each row would correspond to a specific knowledge, skill, or attitude. A (very) small portion of such a matrix is provided in Figure 1 for illustration purposes only, showing three generic CEE courses. This matrix is currently in the conceptual state, but each of the categories of knowledge, skills, and attitudes would be expanded to include the appropriate attributes of a citizen engineer.

	Course 1	Course 2	Course 3
Knowledge (e.g. code of ethics, licensure)			
Skills (e.g. teamwork, communication skills, GIS expertise)			
Attitudes (e.g. appreciation of global and societal impacts)			

Figure 1 Knowledge, Skills, and Attitudes Course Matrix

The Local Infrastructure Report Card: Pedagogies and ABET Assessment

Under the proposed curriculum, students would be required to create chapters of an Infrastructure Report Card, modeled after the Report Card prepared by ASCE. Chapters will be graded as part of the course in which they are written, and we envision a progression of infrastructure chapters as shown in Table 1.

Table 1 Progression of Infrastructure Chapters for the Report Card

Course	"Intensity" Level	"Open Endedness"
New Introduction to Infrastructure course(s)	Low	Low
Junior-level courses	Moderate	Moderate
Senior-level technical electives	High	High

Many details remain, such as determining whether students have to receive a passing grade on each chapter to graduate; inhibiting plagiarism; requiring individual vs. group submissions, etc.

The benefits of the report card are many, and include the following:

- provide practical experience for students in evaluating infrastructure;
- provide students with service learning opportunities;
- provide faculty with an assessment tool;
- increase student awareness of funding mechanisms;
- will not create additional faculty work load, if incorporated properly;
- increase student awareness of analysis, maintenance, and rehabilitation as compared to design; and
- provide an ABET assessment tool.

The last bulleted item merits further explanation. We envision that the report card chapters could be compiled in a single document. This document would then serve as a student portfolio. As such, it would serve as a *direct* measure of student abilities, as compared to indirect measures such as surveys. The use of student portfolios as an ABET assessment tool is well documented.[9,10] The proposed Report Card offers some significant benefits as compared to traditional portfolios, most significantly that students will be required to write the various chapters for various classes. Also, the students will see the benefits of the portfolio as it would be a practical and authentic form of written communication directed to a "real-world" client.

We have also identified a certain number of challenges to incorporating the infrastructure report card. If integrated into the curriculum improperly, the report card could be an administrative headache. There is also a certain cost to sustaining the project. Logistical details could prove challenging, as students need to be transported to the site. The latter concern also raises the issue of student safety on the site; however this could prove to be an opportunity for us to enhance student appreciation of this often neglected topic.

Next Steps

Additional funding will be needed for developing new courses, updating laboratories, and purchasing equipment. An implementation proposal will be submitted to provide these necessary funds.

Besides funding, other issues must be addressed as we implement this new curriculum. Students are a very important constituent of our program, and their input is valued. A small student panel will be formed prior to submission of the proposal to review and provide feedback. Also, graduates of UWP typically enter the workforce immediately, and our graduates have the reputation for having enough practical knowledge to be immediate contributors to projects. Many employers recruit our graduates because of our emphasis on practical education. Our goal with the revised curriculum is to make our students better engineers, so we will seek feedback from practitioners on the proposed changes.

The revised curriculum and courses will need to be brought to appropriate campus committees which are in charge of overseeing academic programs. Once the new curriculum is finalized and approved, a plan will be needed to assist faculty and students through the transition years. Students take different paths to graduation, taking classes in different orders and taking time out for co-ops, international exchange, military service, etc. If classes are removed or significantly modified, a mapping will be devised to assist in advising students who start their schooling under the old curriculum but graduate under the new one.

Conclusion

The Civil and Environmental Engineering Department at UWP has produced a plan to revamp the curriculum in order to better prepare students to take a leading role in improving the infrastructure of the United States. The curriculum will feature new classes on infrastructure topics, will add infrastructure topics to other required engineering classes, and will use some of the general education requirements to help develop graduates with a better understanding of local government. A key component of the new curriculum will be the development, by the students, of a local infrastructure report card, which will be used as an ABET assessment tool. The ultimate goal of this curriculum reform project is to produce citizen engineers that have a better understanding of infrastructure and a more holistic understanding of the built environment.

Acknowledgements

The authors are very grateful for the funding for this study that was provided by the National Science Foundation (Grant EEC-0530506).

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