Engaging Students in Civil Infrastructure Management

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Introduction

Most civil engineering courses focus on design of new facilities rather than on management of existing facilities. However, existing facilities need the attention of civil engineers who are trained with lifecycle concepts and techniques for managing infrastructure, as evidenced in part by the D+ grade awarded to U.S. infrastructure by the American Society of Civil Engineers' *2003 Report Card on America's Infrastructure*[1]. Interest in infrastructure management research and education has been growing among faculty, although the number of courses offered on the topic remains relatively low. Each of the authors teaches an infrastructure management course – one is an upper-level undergraduate elective, one is a graduate-level course, and one course is open to both upper-level undergraduate and graduate students. The authors have worked together to develop and share course materials, as well as to integrate our research into the courses.

This paper builds on two papers previously presented at ASEE Conferences, the 2000 paper "Teaching Students to Manage Civil Infrastructure Systems"[2] and the 2004 paper "Enhancing Infrastructure Management Education through Collaboration."[3] The focus of this paper, however, is on the learning activities we use in our courses. Specifically, we discuss the types of homework and project activities undertaken by our students, the feedback we have received, and our assessment of their value to student learning and in increasing student interest in infrastructure management. It is evident from student responses that those activities that connect theory to practice increase students' interest in the topic and contribute to their understanding of the concepts.

Background

The maintenance and improvement of a community's economic health and standard of living depends on adequate and functioning civil infrastructure systems. These systems include transportation (highways, rail networks, airports, ports, etc.); water, stormwater, and wastewater collection, distribution, and treatment; waste management; energy distribution; parks; and buildings. Design of these systems is clearly specialized, and professionals build on their undergraduate education in structural, geotechnical, environmental, and hydrologic design to develop the systems.

While facility or system design requires specialized knowledge in the appropriate civil engineering sub-discipline, the systems share a number of common attributes. All of these facilities are vulnerable to human-caused or natural disasters, such as terrorist attacks or earthquakes. However, while it is usually not as dramatic, gradual deterioration over time affects all infrastructure, and it costs more money and causes more problems than sudden attacks. The guiding principle of the authors in educating students to manage civil infrastructure is that many of the same principles apply in managing all types of infrastructure, and learning should focus on processes with examples from different types of infrastructure, rather than on the different types of infrastructure themselves.

Although the community of academics researching and teaching in the field of infrastructure management is small, its members have been active in reaching out to one another. For example, workshops held in 2003 and 2004[3] initiated a serious discussion of student enrollments and interest in the field, as well as strategies to overcome some of the barriers to advancement. The history of academic interest in civil infrastructure systems education includes several textbooks [4-6], a number of workshops and conferences, and several series of published articles [7-17] as summarized by Flintsch et al.[3]

The Courses

The courses that the authors teach are outgrowths of a course first taught at MIT in 1987 and revamped by McNeil and taught at Carnegie Mellon University 8 times over an 11-year period. McNeil now teaches the course at her current institution, the University of Illinois at Chicago. McNeil also initiated a similar graduate course in the Master of Science in Infrastructure Systems Engineering program at the University of Minnesota. Amekudzi and Sanford Bernhardt were both students in McNeil's course at Carnegie Mellon and have subsequently initiated similar courses at their current institutions. A more detailed history of the course is described in Amekudzi et al.[2] The following paragraphs describe each of the three courses, including differences in level and background of students.

Amekudzi's course at the Georgia Institute of Technology is titled "Infrastructure Systems" and attracts primarily graduate students, although the course is open to senior-level undergraduates. Most students are from the School of Civil and Environmental Engineering; however, one or two students typically enroll from the City Planning Program in the School of Architecture. The course has been offered once a year since 2000 with enrollments ranging from 4-18 students. It presents an integrated treatment of methodologies, models, tools, funding mechanisms, rules and regulations that assist with managing civil infrastructure deterioration. The course also includes lectures on sustainable development and the built environment. Concepts are introduced to encourage students to think more seriously about the broader social and environmental implications of infrastructure decision making and to encourage students to explore project opportunities for incorporating sustainability into built systems decision making. Students are required to conduct a term project in teams of 2 or 3. The project can either apply the integrated framework presented in the course to evaluate the infrastructure management practice/system of a jurisdiction of the students' choice or focus on an in-depth study of one of the main topics presented in the course (e.g., condition assessment methodologies, deterioration modeling, asset valuation etc.). Written, oral and visual communications lectures have been typically

incorporated in the course and are given by a communication specialist, hired by the School to integrate communication education in the civil and environmental engineering curriculum.

McNeil's course at the University of Illinois at Chicago (UIC) is titled "Infrastructure Management" and is open to graduate students only. The course is cross-listed between Civil and Materials Engineering and Urban Planning and Policy and attracts graduate students from both programs. It is offered yearly and typically enrolls around 20 students. McNeil's course focuses on issues, concepts, and models related to performance of, management of, and resources for infrastructure systems. The variability in background of the students has led McNeil to develop learning activities that are more qualitative than quantitative. Students submit regular homework assignments and complete semester-long projects.

Sanford Bernhardt's course at Lafayette College is titled "Civil Infrastructure Systems Management" and was taught for the first time in Fall, 2004. She had previously taught a similar course twice at the University of Missouri-Columbia (with enrollments of 9 and 31). Lafayette College is a small, undergraduate institution; therefore, the course is an upper-level elective within the Department of Civil and Environmental Engineering. In its recent offering, the course enrolled 10 students, 9 of whom are Civil Engineering majors and one of whom is a Bachelor of Arts in Engineering major. The course is similar in structure to McNeil's, focusing on performance, management, and resources. Students read a number of technical articles, complete a series of homework assignments, and work in teams of two to complete a semester project. The projects are similar to those at Georgia Tech, with considerable latitude given to students to choose a subject in which they are interested.

Learning Activities

In advanced undergraduate and graduate classes in emerging areas, it is challenging to develop activities and assessment tools that advance the learning process, are a fair and effective representation of the learning accomplished in the class, and promote interest is the topic. Individually and collectively we have developed a variety of activities and assessment tools, including writing assignments, hands-on activities, research projects and traditional calculation exercises. These are supplemented with guest lectures from practitioners and researchers, and sometimes field trips. Over the past decade the activities have evolved based on informal student feedback. In this paper we briefly describe the activities and report the results of a survey that asked to students to rate each activity in terms of its contribution to their learning and its impact on their interest in the topic areas.

The activities in the class include homework assignments, a semester-long project, guest speakers, and midterm and final exams. In general, activities involve calculation, interpretation and application of concepts, analysis of data, evaluation, and technical writing. Each of the courses requires students to make at least one presentation. Table 1 summarizes the various activities, classifies them in terms of nature of the activity, and notes the differences among the three courses. The following paragraphs describe some of the activities in more detail; we are happy to provide more detail on any activity upon request.

Table 1 Activities

Activity	Description	Characteristics	Differences
Students determine the extent and condition of a particular type of infrastructure in the United States (HW1)	Research and writing, and some data analysis	Graded Open ended	None
Students conduct a visual condition assessment of a parking lot and report on the data (HW2)	Review of manuals and interpretation of graphs, report writing	Graded Some teamwork	None
Students use and critique deterioration models (HW3)	Calculation and evaluation of results	Graded Relatively prescriptive	Some variations among courses
Students write a critique of the extent and condition of a particular type of infrastructure (HW4)	Reading and writing	Graded	Lafayette only
Students write a critique of a technical paper using (HW4)	Reading and writing	Graded	UIC only
Students complete problems from fundamentals of engineering economics (HW4)	Calculation	Graded	Georgia Tech only
Students complete additional problems from engineering economics (HW5)	Calculation	Graded	Georgia Tech only
Students complete additional benefit costs analyses	Calculation	Ungraded	Georgia Tech only
Students rank and prioritize projects using a variety of criteria including cost benefit analysis (HW6 Pt1, HW5)	Analysis and reporting	Graded Relatively prescriptive	Georgia Tech and UIC only
Students review two articles on pavement management (HW6 Pt2)	Reading and writing Application of concepts	Graded	Georgia Tech only
Students make recommendation on the inclusion of safety and security in infrastructure management	Reading, video and writing Extension of concepts	Graded	Georgia Tech only
Students conduct a "what if analysis" for a infrastructure network using a simulation tool and explore the impact of various infrastructure policies	Use of computer tool and reporting of results	Graded Relatively prescriptive	UIC only
Students attend and report on public meeting related to infrastructure. (HWX)	Writing	Graded	Lafayette and UIC only
Readings: Papers from the technical literature	Reading and classroom discussion	Ungraded except for classroom participation	Not rated at UIC
Projects: Teams or individual conduct projects related to specific applications of infrastructure management; includes progress reports, presentations, and a final report	Research, communication (written, oral and visual), and the application of concepts learned in class.	Graded Semester long	Team projects at UIC
Guest Lectures: A variety of practitioners are invited to make presentations	Questions	Ungraded except for classroom participation	Some variations among courses

Homework assignments typically involve either reading or calculation, analysis, and writing. Some also involve research. An initial assignment in all three courses assigned students different types of infrastructure (for example, bridges, drinking water, etc.) and asked them to report on its extent and condition in the United States. Another assignment asked students to conduct a visual condition assessment of a pavement segment on campus. For this assignment, students were provided with a condition assessment manual and instructions for computing the Pavement Condition Index (PCI), and they were asked to report their findings in writing, as well as to critique the process. A third assignment asked students to attend a public meeting at which infrastructure issues were likely to be discussed (for example, a city council meeting), and report on the process for public involvement. Many of the students have never attended a public meeting prior to this assignment.

None of the three courses uses a textbook. Instead, students are assigned readings from the technical literature throughout the course. While some of the articles were common to all three courses, not all were. In some earlier iterations of the courses, students were asked to write summaries of a number of "key" papers over the semester. However, we found that students were often summarizing without really understanding the readings, and the students looked at the summaries as busy-work. This semester, the UIC students completed a paper critique as a homework assignment, and the Georgia Tech students reviewed articles as a homework assignment as well. At Lafayette, students were instructed to come to class prepared with questions and comments about the assigned readings, and a significant portion of the day's class was devoted to discussion of the article(s). Most of the undergraduate students and many of the graduate students did not have much experience with reading technical literature prior to this course.

All three courses ask students to complete a project in which they either apply a range of concepts from the course or investigate one topic in depth. At Georgia Tech and Lafayette, students were encouraged to select a local municipality, investigate the condition of a type of infrastructure and the municipality's current management practices, and make recommendations for improving those practices, including the development of a conceptual plan of an appropriate management system where necessary. At UIC, students developed a concept plan for a specific type of infrastructure for a local city or township.

The courses included a wide range of guest speakers. Speakers vary from one offering to the next based on speaker availability as well as topical issues. Typically, speakers are drawn from local public works managers, state DOT infrastructure managers, and private consultants working on infrastructure renewal projects. At UIC, the Public Administration Capital Budgeting course is taught at the same time as the Infrastructure Management course so that the two courses can share guest speakers. Speakers included a representative from an investment firm, a local reporter who covers infrastructure issues, an executive director of a local infrastructure advocacy organization, and a local pavement management consultant.

In addition to the activities listed in Table 1, a midterm and final exam are administered in all three courses. These are typically a critique of a technical paper or the application of the concepts to a new domain, and they are often assigned as take-home exams. For example, students might be asked to read a journal article describing a new model, summarize the goals of

the model, classify the model based on concepts learned in class, compare it to other models studied, and critique its usefulness. Alternatively, they may be asked to propose a management system (including goals, architecture, and types of models) for a class of infrastructure not discussed in detail in class that semester.

Assessment

Over the years that we have taught these courses we have solicited informal feedback from students in addition to the feedback we have received through standard institutional student course ratings and comments. Our sense had been that students really liked the condition assessment exercise (HW2) because of the chance to get out in the field, but we didn't have a good idea about the other course activities. Because end-of-semester evaluations focus on the course as a whole, we rarely received feedback on any particular aspect of the course.

In addition to our curiosity about how much the students are learning from the different learning activities, we are also interested in the effects of the activities on student interest in the subject, which also is not typically addressed in standard course evaluations. As a result, at the end of the Fall, 2004 semester, we asked students to complete a survey that asked about both the learning and interest stimulated by a variety of course activities. Because the three courses are different, the surveys were not identical, but they followed the same format. For each activity, the survey asked the students to rate their level of agreement with two positive statements reflecting (1) their understanding of the topic and (2) their interest in the subject. All surveys used a Likert scale of five choices ranging from "Strongly agree" to "Strongly disagree," with the middle rating "Neither agree or disagree." In addition to the Likert scale responses, student comments were invited on each activity. Figure 1 shows an example of a portion of a survey.

Table 2 summarizes the results of the surveys in terms of the percentage of students that either "Strongly agreed" or "Agreed" with the statements. The abbreviations used for each of the activities are also included in Table 1 along with the activity descriptions. Figures 2 and 3 present the responses for each of the activities for all three courses in terms of "understanding" and "interest" respectively. Ten students responded at Lafayette College, four at Georgia Tech and seventeen at UIC. Because of the small sample sizes, we did not attempt to conduct any statistical analysis. Instead, we focused on our overall impressions of the responses and some anecdotal evidence of our successes and activities that need improvement.

The results of the survey showed that, overall, students agreed or strongly agreed that the activities contributed to their learning. The data related to stimulating student interest were not as positive. The graduate students appear to have a greater interest in the subject than do the undergraduate students. However, the undergraduate students voluntarily provided extensive feedback in the form of comments, which were both positive and constructive.

The lower proportion of "Strongly Agree" and "Agree" responses from UIC reflects the diverse backgrounds of the class. Some students were taking the class to fulfill minimum coursework requirements; others came from planning backgrounds, and one came from public administration. Almost every activity had someone who really did not see any value to the activity, and largely these unenthusiastic responses came from two students.

CE 444

Civil Infrastructure Systems Management

Department of Civil & Environmental Engineering, Lafayette College
Fall 2004

Course Activity Survey

I am interested in understanding how elements of the class contributed to your learning of the subject matter and interest in the topic. Your responses will be used to improve the course.

For each course activity described, indicate your level of agreement or disagreement with the following statements. Please include comments, if you have any.

Homework 1 asked you to research the extent and severity of the deterioration of a specific type of infrastructure.

I understand national infrastructure issues.	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
This homework increased my interest in the subject.	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree

Comments:

Homework 2 asked you to conduct a visual inspection of the parking lot and report on the results and the process.

I understand the practice of condition assessment.	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
This homework increased my interest in the subject.	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree

Comments:

Figure 1. Course activity survey example

Table 2. Survey Results – Percentage of Respondents that "Strongly agree" or "Agree"

Activity	Understanding			Interest		
	Lafayette (10)	GaTech (4)	UIC (17)	Lafayette (10)	GaTech (4)	UIC (17)
HW1 - Extent	100.0%	100.0%	94.1%	40.0%	100.0%	94.1%
HW2 - Cond. Assess	100.0%	100.0%	94.1%	70.0%	100.0%	88.2%
HW3 - Det. Models	90.0%	100.0%	94.1%	33.3%	50.0%	64.7%
HW4 - Critique HW1	90.0%			20.0%		
HW4 - Paper review			88.2%			82.4%
HW4 - Econ		75.0%				
HW5 - Econ2		75.0%				
B/C (ungraded)		75.0%				
HW6 Pt1 Rank/Opt		75.0%	82.4%		50.0%	82.4%
HW6 Pt2 Opt Articles		75.0%			50.0%	
HW7 - valuation/security		50.0%			75.0%	
HWX - Public Mtg	90.0%		82.4%	40.0%		76.5%
Readings	70.0%	100.0%		50.0%		
Project	90.0%	100.0%	88.2%	90.0%	100.0%	76.5%
Guest Lectures	100.0%	75.0%	94.1%	90.0%	50.0%	64.7%
Project Progress Reports			94.1%			

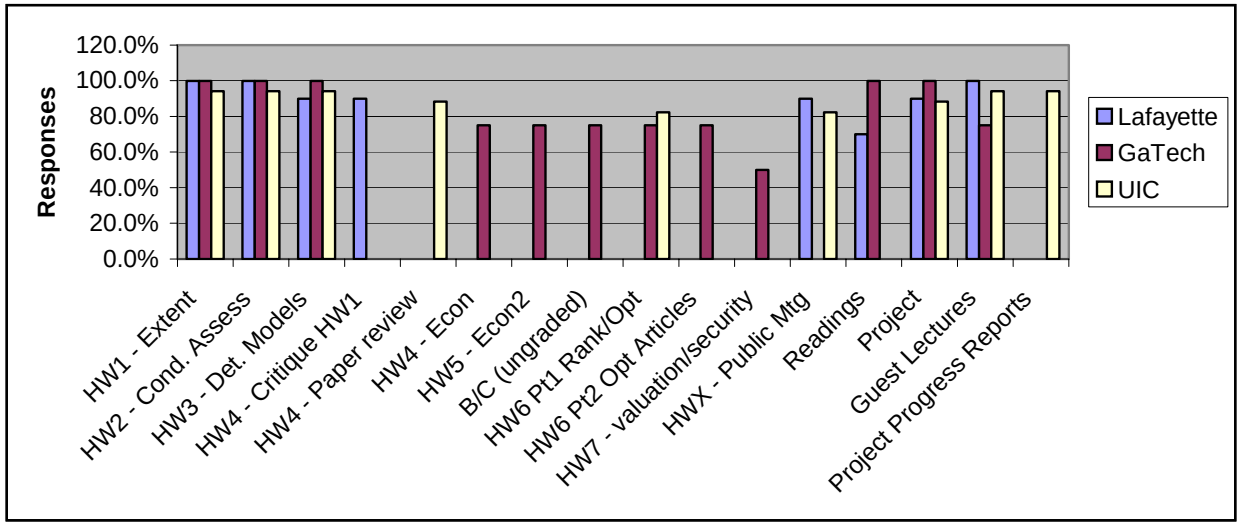

Figure 2. Summary of responses in terms of student understanding. (Respondents that "Strongly agree" or "Agree")

Students overwhelmingly thought they learned from the assignment in which they attempted to determine the extent and condition of one type of infrastructure (HW1). However, in spite of being provided with an example for pavements, the Lafayette students were frustrated by the open-ended nature of the assignment, particularly as a first assignment in a new course ("This homework was engaging but may have been a little extensive given our lack of knowledge in the field"). Several students also suggested that the students share their results with one another upon completion of the assignment, which we believe is an excellent idea.

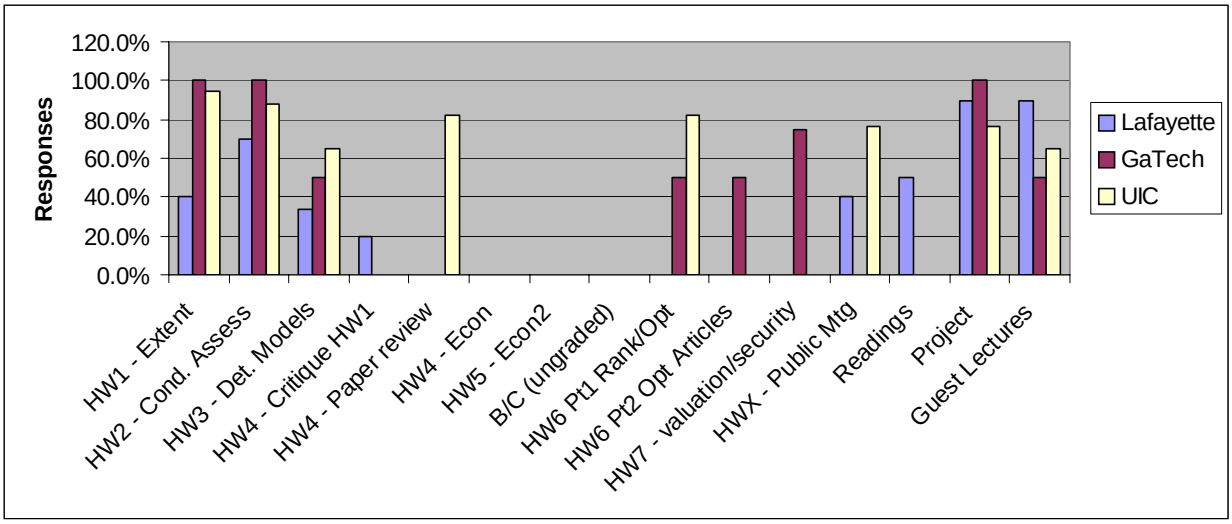

Figure 3. Summary of responses in terms of student interest (Respondents that "Strongly agree" or "Agree")

The condition assessment exercise (HW2) is the most structured and the most hands-on activity. As we expected, this assignment was consistently ranked highest in all three courses. This ranking is also supported by the comments:

- Anything where we are actually "doing" some infrastructure management task is better than if we read or hear about how it is done. (Lafayette)
- The hands-on experience really helped me understand condition assessment. (Lafayette)
- I liked this homework. This is the first time that I did visual inspection on pavement. It was fun and I learned a lot. (UIC)

The students also appreciated that project and the guest lectures. Comments included:

- Great project. (Lafayette)
- Good selection of a variety of speakers. (UIC)
- Having people with real world experience in things like public works department and private firms is helpful in understanding how infrastructure is managed. (Lafayette)

From our point of view, the students were generally interested in the projects and motivated. The presentations and final reports were, on the whole, quite comprehensive.

The activity labeled HWX, requiring attendance at a public meeting, received variable responses. This homework was introduced at UIC in 2003 and informal feedback and the insights presented in the written reports suggested that this was a valuable **and** interesting experience. The written reports were again enthusiastic, but the UIC survey responses were consistent with other activities. The Lafayette surveys yielded similar results. One of the frustrations reflected in student comments on the survey (as well as in informal conversations) was the relative lack of time spent on infrastructure issues at the public meetings attended. As one Lafayette student stated, "This was a good experience and really somewhat a scary taste of reality." We agree!

Student responses to the course readings were mixed. Some of the students found them interesting ("I liked the comprehensiveness and 'currentness' of the readings" (Georgia Tech)), while others found them challenging ("I had a very hard time with the readings" (Lafayette)).

For students who have little experience in reading technical literature, and even less experience in the infrastructure management discipline, the readings are, indeed, difficult. At UIC, McNeil spent time informally with her students discussing "how to read the literature." For example, she instructed her students to read the Abstract, Introduction, and Conclusion first, then tackle the rest of the paper. Another idea we might try is to ask students to annotate each paragraph with its main idea. Whatever the approach, it is clear that we need to spend more time working with our students on how to read the literature if they are to learn from it.

The Georgia Tech surveys also included an open-ended question asking which activities were most helpful. The written responses were encouraging:

- Really, everything was helpful. I liked the "practicalness" of the homework.
- This was a very hands-on course. The homeworks involving solving problems were more helpful than the ones requiring summarization of articles.

Conclusions

Our evaluation has not changed our view that a systems approach to infrastructure management is critical for students. It provides students with a perspective not found in other courses and requires them to address complex, open-ended problems integrating engineering knowledge with economics and management principles. We are pleased that we have challenged our students, increased their understanding of the subject areas, and in some cases interested them in the topic. We have found that the hands-on activities are helpful, but they should not take the place of some of the more traditional calculation and analysis exercises. In addition, compared with the typical engineering class, we ask the students to do a lot of writing and classroom presentation; we also think the emphasis on communication is important. The undergraduates appear to be more demanding and are more challenged by the open-ended activities, which is not surprising. The responses to the questions also provide us with some areas where we need to revisit the activities during class time (for example, discussing the results) or explaining how to read a technical article.

The collaboration among the faculty from different institutions is making the course better, for example, sharing the problem sets and notes, and discussing strategies for engaging the students. We believe we have developed some effective activities and are willing to share these with other colleagues. We are also interested in learning of the experiences of other colleagues as we continue to revise and improve our courses.

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