The Civil Engineering Systems Course at Georgia Institute of Technology

Adjo Amekudzi, Ph.D.[1]
Michael Meyer, Ph.D., P.E.[2]

Abstract
A course entitled "Civil Engineering Systems" was introduced in the fall of 1999 as a required course in the undergraduate curriculum, at the School of Civil and Environmental Engineering at Georgia Institute of Technology. This course introduces students to a systems perspective on civil infrastructure and services and to the concept of sustainability as it relates to the planning, design, construction and operation of civil engineering systems. These concepts are introduced in various aspects of problem-solving, including problem definition; use of analysis tools for evaluating the performance of facilities and services; incorporation of benefits and costs into decision-making, and the assessment of environmental and social impacts. This paper presents the key features of the course.

Introduction

In 1992, Georgia Tech received a grant from the General Electric Foundation to create the Center for Sustainable Technology, now the Institute of Sustainable Technology and Development (ISTD). One of the major goals of the Center (Institute) was to emphasize sustainability as a major goal for Georgia Tech in all aspects of research and education as well as in the operations of the campus itself (Chameau, 2002). In 1995, the University adopted a vision that explicitly included sustainability: "*Georgia Tech seeks to create an enriched, more prosperous and sustainable society for the citizens of Georgia, the nation and the world*." In response, the School of Civil and Environmental Engineering, one of the major focus points for sustainability on campus, developed a new course called "Civil Engineering Systems" that incorporated not only sustainability into its material, but also adopted a systems perspective on civil-engineered facilities and services.

The creation of this course coincided with a decision in 1995 by the Board of Regents of the University System of Georgia to switch from a quarter- to a semester-based system. In its decision, the Board encouraged academic units to take advantage of the opportunity to develop new courses and to incorporate new content into their curriculum. With such an opportunity, the School of Civil and Environmental Engineering updated their curriculum to introduce and emphasize

---

[1] Assistant Professor, Transportation Systems Program, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355, Tel: 404-894-0404, Fax: 404-894-2278, Email: adjo.amekudzi@ce.gatech.edu

[2] Professor, Transportation Systems Program, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355, Tel: 404-894-0404, Fax: 404-894-2278, Email: mike.meyer@ce.gatech.edu

more strongly the concepts of sustainability, systems, technical communications, and computer-based analysis and design. In 1999, a new course: "Civil Engineering Systems" (CEE 3000), introduced one of the biggest changes in the curriculum and served as a point of departure for subsequent, more specialized, courses in the civil and environmental engineering curriculum.

This paper discusses the key features of the Civil Engineering Systems course, including the course content, the technical communications and distance learning components, how the course fits within the overall curriculum, progress and lessons learned from four years of offering the course, and continuing course development.

Civil Engineering Systems at Georgia Tech

The Civil Engineering Systems course presents civil infrastructure as a system, consisting of various interconnected components and having strong external relationships to the surrounding environment. Modeling approaches, engineering economy, project evaluation, impact analysis, and multicriteria evaluation are taught from a broad perspective that includes life cycle and sustainability concepts (Meyer and Jacobs, 2000)

The course, which is required in the undergraduate curriculum, enrolls 150 to 200 students every year, predominantly sophomores and juniors. It is offered twice a year in the fall and spring semesters both to students on campus and via the distance-learning program to students in the Georgia Tech Regional Engineering Program (GTREP). Typically, 30 to 45 students enroll every year from Armstrong Atlantic State University and Georgia Southern University in southern Georgia. The course is offered to on-site and off-site students simultaneously with faculty/student and student/student interactions occurring in real time via visual and audio satellite connections.

Course Objectives and Outcomes

The undergraduate civil engineering program at Georgia Tech has, as a guide, an adopted set of desired outcomes. These outcomes serve as the basis for the program's ABET[3] accreditation process. The Civil Engineering Systems course, in particular, is designed to achieve the following outcomes in student skills and expertise:

1) Understanding civil engineering solutions in a global, societal and environmental context, consistent with the principles of sustainable development
2) Solving engineering problems by applying fundamental knowledge of math, science and engineering
3) Identifying, formulating and solving civil engineering problems that meet specified performance, cost, time, safety and other quality needs and objectives

---

[3] Accreditation Board of Engineering and Technology

4) Working and communicating effectively both individually and within multidisciplinary teams
5) Obtaining a solid understanding of professional and ethical responsibility, and a recognition of the need for and ability to engage in life-long learning
6) Experiencing an academic environment that facilitates and encourages learning and retention

Upon completing the course, the student is expected to be able to:

1) Explain how the concepts of systems and sustainability are relevant in the planning, design, operation and maintenance of engineering projects
2) Evaluate quantitatively the performance of civil engineering systems
3) Use engineering/economic decision making tools to identify the best economic project alternative
4) Discuss the limitations of economic decision tools for incorporating environmental and social impacts in the planning, design and operation of engineering projects
5) Discuss approaches for incorporating environmental, social and equity considerations in the planning, design and operation of engineering projects, and
6) Demonstrate the basics of professional technical communications (written, oral and visual).

Technical communications are an important component of the course as the objectives and outcomes indicate. Because this course is one of the first civil engineering courses offered to the students, it is designed to provide them with in-depth exposure to professional communications skills and strategies. The School hired a full-time communications professional in the mid-1990s to work with civil engineering students throughout their academic career. This professional has been dedicated to the Civil Engineering Systems course as a means of introducing key communications concepts early in the academic program.

Course Organization

The course is divided into three major sections or modules as described below:

Systems and Sustainability Perspectives (Module 1)

In this module, the students are exposed to the concepts of systems and sustainability, and develop an understanding of how such perspectives can be useful to civil and environmental engineers in the context of global trends in resource consumption, waste generation and the impacts of engineering decisions on the natural and human environment. Specifically the following questions are addressed: What are systems? What is sustainability? How do these concepts relate to engineering planning, design, construction, operations and maintenance? How do engineers represent systems in order to analyze their performance? How can we mathematically evaluate system performance? How do engineers consider demand and capacity issues in project planning to solve pertinent problems?

Systems Performance Analysis (Module 2)

The second module addresses the modeling of infrastructure systems. The module presents several techniques that can be used to measure or optimize the technical performance of systems, e.g., system optimization through the application of calculus, linear programming, queuing theory, computer simulation, and probabilistic methods for incorporating uncertainty in systems problems. The module also addresses the limitations of these techniques, especially with respect to considering non-quantifiable impacts, in particular sustainability.

Economic Decision-Making Tools and Project Evaluation (Module 3)

This final module focuses on economic decision making. It introduces students to the tools that help them identify the “best” economic alternative among those under consideration. Techniques such as the net present worth, internal rate of return and benefit-cost ratio methods are covered for identifying and comparing feasible alternatives. Also covered are relevant questions on how we consider non-monetary benefits and costs in our assessments, e.g., the positive or negative effects on sustainability. In addition, the module covers the various types of assessments that are performed to capture environmental and social impacts; mitigation strategies are used to reduce or minimize environmental and social impacts, or proactive environmental preservation strategies being considered in the planning stages. In addition, the module presents an introduction to infrastructure management, addressing how engineers systematically manage operations and maintenance once a facility is constructed and service begins.

A course reader, consisting of various articles on systems, sustainability, engineering economy, environmental and social impact assessments, and infrastructure/asset management, is used to complement the material presented in the course.

Course Project

The final weeks of the semester are reserved for team-based project presentations. Every student must be part of a project team (of 4 to 6 individuals) that examines a civil engineered facility, service, or system using the integrated systems/sustainability framework presented in the class. The framework must incorporate a multidisciplinary perspective that includes the technical, economic, environmental and socio-political elements of the project. It must also include a life cycle perspective of the project and focus on the interaction of the project with its larger natural and human environment. The students are expected to apply the tools they have learned in the three modules to examining the facility, system or service of their choice. Over the course of the semester, each team gathers information on their chosen topic and must answer the following questions in both a written report and an oral presentation:

1. What purpose does the facility/system serve?
2. What are the basic functional characteristics of the object being studied?
3. From a systems perspective, what are the linkages/relationships between the facility/system and the broader environment and community?
4. What analysis tools/models are (or could be) used to assess the performance of your facility/system?
5. From a sustainability perspective, what strategies or actions could be adopted to make the facility/system performance more sustainable?
6. How are benefits and costs defined for improvements to this facility/system?

Examples of project topics chosen by students include the following:

--Hurricane evacuation of a coastal city
--Airport security from a systems perspective
--Building heat and ventilation systems
--Waste generation and handling on campus
--Development of a large development site
--Campus transportation
--Water treatment and distribution for a city
--Cruise ship
--Roman aqueduct systems
--Transportation systems, including roads, transit, airports, and ports
--Heat generation on campus
--Wastewater treatment
--River conservation
--Regional or city waste handling
--Electric power generation
-- Landscape irrigation
--Project management
--Space station
--Interstate water conflicts

Engineering Communication

As noted above, an important objective in this course is to develop student skills in technical communication. The School of Civil and Environmental Engineering has a full-time technical communication specialist who participates in this course and works closely with students in written, oral and visual presentation of material. The specialist presents lectures on effective communications skills in the context of civil engineering systems and sustainability. Thus, the communications content is integrated into the course material rather than presented as a separate topic with non-civil engineering examples. Both the lead professor and the communications specialist grade homework and project assignments so that students understand the importance of communications in the effectiveness of their work. Given that this course is usually taken at the beginning of a student's academic program, the strong exposure to communications typically has lasting benefit for the student in courses that come later in the curriculum.

Linkage to Subsequent Courses

This course was designed to act as a basic point of departure for systems and sustainability concepts presented in the rest of the civil and environmental engineering curriculum. The faculty agreed early on that sustainability cannot be effectively taught only in one course in the curriculum, but must be an underlying theme throughout the curriculum, as several others have noted (see for example Gunn, 1996; Barger and Hall, 1998). Several other technical courses have adopted a systems perspective in their material (including adding the term "systems" to their course title). Examples include Environmental Engineering Systems (CEE 4300) and Geosystems Engineering (CEE 4400). Several construction engineering courses, such as Construction Engineering and Management (CEE 4100), also have systems and sustainability underpinnings. As new material is developed, other courses are modified to integrate systems and sustainability into the curriculum on a continual basis.

Assessment, Lessons Learned and Next Steps

One of the important questions for any instructor of a college course is: how well is the course meeting the objectives for which it was designed? The only quantitative data on student assessment occurs as part of the student course evaluation process; however, various other qualitative performance indicators also reveal what students are learning from the course. In addition, comments from end-of-semester teaching evaluations and senior exit interviews are used to obtain feedback from the students on their experiences in the course.

In general, homework and project assignments as well as quizzes and exams reveal significant progress in written communications judged from the quality of writing at the beginning and end of the course. The term projects measure students' abilities to think in broader systemic terms about the sustainability implications of the facility/system/service of their choice. Students' choices and use of multidimensional criteria for systems analysis reveals the extent to which they have understood and can apply the broader systems/sustainability framework to assess engineering facilities, systems and services. The project in particular tests how well students can identify and apply the appropriate mathematical models for evaluating system performance and engineering-economic decision tools for evaluating proposed system improvements. Subsequent transportation courses taught by the course instructors have generally shown that the concepts taught in the civil engineering systems course are remembered, and can be applied by students in more advanced problem solving. The qualitative discussion on environmental and social impacts as well as a demonstrated understanding of the political factors constraining or otherwise affecting proposed system improvements also reveals how far students have progressed in thinking about civil engineering in a more global/societal context.

Comments received through the end-of-semester evaluations and annual exit interviews have been very positive with many students indicating that the course has given them a new way to view societal problems and engineering solutions. Many students have identified it as one of the best courses taken during their academic program at Georgia Tech. A number of students have indicated an interest in graduate level studies in this multidisciplinary concentration area.

Important considerations in on-going course development have included achieving an appropriate balance between the depth and breadth of the material covered. The approach used to address this issue has been to present a broader overview of systems and sustainability-related problems in civil engineering at the beginning of the course (in module 1) and then follow this with a more in-depth coverage of analytical methods and decision analysis tools for systems performance and alternatives evaluation (in modules 2 and 3). The term project then offers the students an opportunity to integrate the broader qualitative knowledge with the more in-depth quantitative methods to address sustainability improvements in their facility, system or service of choice. An important lesson learned has been the value of mid-semester peer evaluations for setting the expectation for substantive contributions from each individual in the team. In addition, students have been given the opportunity to provide feedback on the course during the semester. Such feedback has resulted in refinements in various elements of the course such as instructor modifications of the course reader material, and preparation of material on engineering economy that is more appropriate for civil engineering students.

Continuing refinement of the course content is a priority as more examples of sustainability-oriented civil engineering initiatives become available, and parallel efforts to create a systems/sustainability basis for civil and environmental engineering curricula come into place and continue to progress both within the United States and in the international community (see for example Siller, 2001; Van Kastern, 1996; and Gunn, 1996). One of the next logical steps for continuing development of the course material is the development of a formal textbook on civil engineering systems and sustainability. Such an effort will integrate the key components of the course material, currently found in various textbooks and articles, and continue to formalize this multidisciplinary concentration area.

Summary

This paper presents an overview of the “Civil Engineering Systems” course at Georgia Institute of Technology. Required in the undergraduate curriculum since the fall of 1999, the course represents an important change in direction for the program by introducing a systems/sustainability basis for the curriculum. This change is part of a broader, systemic institutional initiative to incorporate sustainability in Georgia Tech’s research, education and economic development programs. The intent is to have this course feed into other courses in the civil and environmental engineering curriculum. The course introduces students to systems and sustainability perspectives in the planning, design, implementation and operation of civil engineering systems. The concepts are introduced in various aspects of problem solving such as problem definition, use of analysis tools for evaluating the performance of facilities and services, incorporation of benefits and costs into decision-making, the assessment of environmental and social impacts, and the post-construction management of civil-engineered facilities and systems as assets. Technical communications are an important component of the course taught by a communications specialist hired by the School. The course is also offered via the long distance education program to students in the Georgia Tech Regional

Engineering Program (GTREP) in southern Georgia. Course assignments, teaching evaluations and exit interviews indicate that the course is effective in achieving the goals for which it was designed. Course refinement remains a priority as sustainability-oriented developments in civil engineering continue to appear and similar efforts to introduce a sustainability and systems basis for civil engineering curricula occur around the country and in the international community.

References

Barger, Marylyn and M. Wayne Hall (1998). Sustainability in Environmental Engineering Education, *1998 Annual Meeting of the American Association for Engineering Education*, American Society for Engineering Education (ASEE), Washington, D.C.

Chameau, Jean Lou (2002). Transforming a large research institution, In *EFS (Education for Sustainability) Profiles*, Second Nature Website, Accessed at http://www.secondnature.org/efs/profiles/profile_georgia.html in February 2004.

Gunn, I. W. (1996). Education for Sustainability through Engineering, **Environmental Engineering Education and Training**, Eds. T. V. Duggan and C. A. Brebbia, Computational Mechanics Publications.

Meyer, Michael and Laurence Jacobs (2000). A Civil Engineering Curriculum for the Future: The Georgia Tech Case. *ASCE Journal of Professional Issues in Engineering Education and Practice*, Vol. 126, No. 2, April 2000.

Siller, Thomas J (2001). Sustainability and Critical Thinking in Civil Engineering Curriculum, *Journal of Professional Issues in Engineering Education and Practice*, July 2001.

Van Kastern, Johannes M. N. (1996). Interdisciplinary Teaching within Engineering Education, *European Journal of Engineering Education*, Vol. 21, No. 4.