# Integrating Sustainability into Civil Engineering Curricula

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## Introduction

As U.S. civil engineers debate the body of knowledge that should be a part of civil engineering education under American Society of Civil Engineers (ASCE) Policy 465[2] or within current undergraduate curricula, one component not commonly included in current curricula but absolutely fundamental to our graduates is sustainability. Sustainable development is defined by the United Nations World Commission on Environment and Development[11] as "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs..." It is well documented that a worldwide crisis is approaching if sustainability does not become a fundamental consideration in development.[10]

ASCE recognizes this need, as documented in its first fundamental Canon of its Code of Ethics: "Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.[3]" Sustainable engineering is already a major consideration for construction of many federal projects, and many industries are also recognizing that sustainable design leads to better, more economical, longer lasting facilities that are people-friendly. Inevitably, much of major construction in the coming decades will feature sustainable design and construction processes.

Sustainability must become a fundamental consideration in all civil engineering design and construction. As the leaders of change in fundamental civil engineering processes, it is the responsibility of civil engineering departments nationwide to lead the movement toward sustainable civil engineering development through research and education of their students. The ASCE code of ethics suggests that failure to do so is a breach of civil engineering education ethics. In addition, to make sustainability a fundamental consideration in all civil engineering work is simply good engineering. Through sustainability, civil engineers can elevate the level of engineering to reduce life-cycle and beyond life-cycle costs through only moderate additional engineering costs. An additional selfish but valid aspect of sustainable civil engineering development is that it increases the engineers' role in development.

Groundbreaking, funded work in development of civil engineering curricula to include sustainability is well documented.[6,7,8,9] This work has been done by early leaders in civil engineering sustainability education, often with the assistance of funding. This work is a resource for other departments, but may not address hurdles to sustainability education faced in other departments. For example, the majority of civil engineering faculty are not knowledgeable about sustainability, and department leaders may not perceive the magnitude of the need. Once convinced of the need for sustainability education, faculty may ask what is the scope of fundamental sustainable engineering knowledge and tools required by civil engineering graduates? The pinch to fit more material into crowded curricula while reducing total credit hours is well recognized. Where can additional material be added and who will pay for it?

At Rose-Hulman Institute of Technology (RHIT), sustainability has been a part of the environmental and water resource engineering courses and curricula for years. However, sustainability learning was faculty driven rather than driven by department initiative, and departure of that key faculty put the growth of sustainability learning in the department at risk. We also noted that focusing sustainability within environmental courses caused some students in other civil engineering subdisciplines to dismiss sustainability as not relevant to their interest. The RHIT Department of Civil Engineering is now working to make sustainability a department initiative and a consideration in all of its civil engineering design and construction education. Due to the credit hour crunch, we are working to incorporate knowledge about and tools for sustainability without increasing credit hours or eliminating existing course content. We are working to do this through infiltration of sustainability into our courses.

**Design of Student Activities in Sustainability**

Infiltration of sustainability into civil engineering curricula should be systematic, considering the knowledge and skills to be acquired by students and the desired learning outcomes while setting priorities to assure efficient implementation. We sometimes favor a systematic "backward design" process[13] to plan learning activities, and sometimes we just proceed with a good idea while assuring our experimentation is not risking the quality of the educational process. For planning purposes, learning may be classified into four domains: cognitive, psychomotor, affective, and social[5]. Traditional engineering learning begins in the cognitive domain, though we recognize that social, psychomotor, and affective learning is also crucial to total learning. In the cognitive learning domain, the lowest level of learning is knowledge, with successively higher levels being comprehension, application, analysis, synthesis and evaluation.

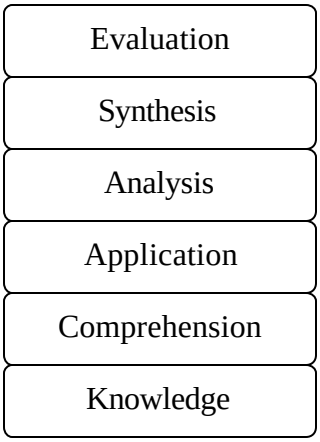


Figure 1. Levels of learning in the cognitive domain

Sustainability should infiltrate learning at the lowest cognitive levels first, with that learning then being built upon by activities at higher learning levels. Learning sustainability can be enhanced by activities that elicit an emotional response (affective domain) and an understanding of the affect of sustainability on quality of life (social domain). Project work that includes sustainability considerations improves learning in the social and affective domains as well. We propose that knowledge, comprehension and application of sustainability be the initial focus of learning in civil engineering curricula while taking advantage of both social and affective learning activities to improve knowledge retention and broaden sustainable development learning.

**Infiltration of Sustainable Issues into the Curriculum**

We are just beginning the infiltration of sustainability into our civil engineering curriculum. Based on informal discussions among ourselves a preliminary strategy has evolved that includes, in order of possible integration:

- Selection of curriculum content
- Retaining, with modifications, sustainability in our ENVIRONMENTAL ISSUES course
- Adding sustainability to design problems in required courses
- Including sustainability in our capstone design courses
- Developing civil engineering faculty buy-in leading to regular dialogue with students on sustainable development issues in existing courses freshman through senior year

With most Civil Engineering departments adding more content to a fixed or decreasing number of credit hours, the appropriate selection of sustainability curriculum content is critical. ASCE Policy Statement 418[1] on the role of the civil engineer in sustainable development states that "sustainable development requires broadening the education of engineers" and that among other things civil engineers should:

- "Cultivate a broader understanding of political, economic, technical and social issues and processes related to sustainable development"
- "Acquire the skills, knowledge and information to facilitate a sustainable future"

The American Society of Engineering Education (ASEE), within its statement on sustainable development education, states that "engineering graduates must be prepared by their education to use sustainable engineering techniques in the practice of their profession and that engineering faculty teach pollution prevention techniques, life cycle analysis, industrial ecology and other sustainable engineering concepts.[4]" Clearly, our civil engineering graduates are expected to know something about sustainability. The broad nature of both civil engineering and sustainability makes determining that something difficult. Based more on faculty interest and expertise than reasoned analysis the following topics are being addressed in our curriculum:

- Basic knowledge – the fundamental concepts of sustainable development and their implications on the engineering practice
- LEED - Green Building Rating System[12]
- Geotechnical consideration of using recycled materials in earthwork
- Recycled materials in transportation (asphalt, etc.)
- Recycled materials in construction/deconstruction
- Natural resource management (currently focusing on water resources)

Continuous evaluation of the course content and assessment of student learning and interest will aid us in refining the content presented in the curriculum. Note the content is not restricted to traditional environmental courses. We believe it is crucial for students to hear from non-environmental faculty who are passionate about sustainability. Faculty buy-in outside of environmental engineering is crucial to student buy-in, because students need to believe, through the example of faculty in a variety of civil engineering subdisciplines, that sustainability is a challenge to all civil engineers and not just a topic delegated to environmental engineers.

ENVIRONMENTAL ISSUES, a required junior-level course, has been part of the civil engineering curriculum for several years and was developed to address the interrelated issues of population, land and food resources, water resources, energy resources and human health in the environment and to expose civil engineering students to current environmental issues. The course content has

varied based on departmental needs and faculty interest but has focused on the science behind current environmental issues. The goal was to provide our students with the knowledge to make policy decisions based on scientific analysis rather than pseudo-science, emotional response, or politics. The inclusion of sustainability has, however, been at the option of the instructor.

ENVIRONMENTAL ISSUES is the course where we introduce the basic knowledge of sustainability to our students and address specific applications of sustainability in the practice of engineering. Sustainability is in excellent agreement with the original objectives of the course. Although we do introduce new content into our curriculum without increasing credit hours we do sacrifice an equal amount of content from the course. Complex environmental issues, such as global warming, require interdisciplinary knowledge to fully understand. It is unlikely that in a single course we can provide the knowledge to permit students to make policy decisions based on the science of such complex issues. However, what we can provide them in a single course is an understanding of the importance of sustainability and how sustainable design will aid in solving complex environmental issues. This trade in course content improves the quality and value of the course. We are not conceding the critical and important role of civil engineers in establishing environmental policy but recognizing where best to place that role. ENVIRONMENTAL ISSUES is structured to address the lower learning levels of the cognitive learning domain: knowledge, comprehension and application of sustainability. Based on an in-class survey of student's environmental attitudes many civil engineering students bring an environmental consciousness to the course which enhances learning opportunities through the affective domain of learning. The use of case studies and real-world civil engineering applications enhance comprehension and application learning.

INTRODUCTION TO DESIGN is a required freshman course featuring teams of three or four students working on real civil engineering design projects for real clients. In addition to the project-based group learning, students are introduced to six different topics fundamental to success in civil engineering. The cognitive learning focus in these modules is language development and comprehension. The topics are communication of engineering design, being a professional, time management, ethics, sustainability, and engineering business management. In the sustainability module, students are asked to reflect on their role as engineers in sustainable development and the sustainability of their project design. Each year, the class makes a trip to a major city (either St. Louis, Chicago, or Cincinnati) to visit engineering projects and meet with engineers. We include a sustainable engineering project as one of the visits during this yearly trip.

Sustainability is currently infiltrating the required sophomore class, MECHANICS OF MATERIALS. This class has included behavior of elasto-plastic materials, composite beams and columns, and similar structural components, but focused on the properties of manufactured plastics, timber, and metals. Sustainability is now being introduced through several class assignments considering the material behavior of recycled materials, such as plastic residential decking. These assignments merely replace others dealing with materials that can be modeled as elasto-plastic, so there is no loss of content with the revision. Students will consider how the engineering behavior of these materials will affect design of a simple engineered system, and will be asked to reflect on the significance of sustainability to their work as designers. Cognitive learning occurs at the language development, comprehension, application and analysis levels.

The required junior year class, SOIL MECHANICS, has had limited exposure to sustainability through faculty expert dialogue and case history presentations about using fly ash and similar materials as structural fill. This constitutes language development and comprehension levels of cognitive learning. To this point, no class assignments have included sustainable earthwork, but the instructor for that class is currently developing a laboratory and multi-lecture module addressing use of recycled materials in earthwork. This will raise the cognitive learning to the analysis level. This class is project-based and developed to provide exposure to geotechnical engineering investigation and design. Inclusion of these new modules will not require loss of content as the students will merely be considering shear strength, compressibility and index properties of a non-natural material rather than natural soil.

CIVIL ENGINEERING CODES AND REGULATIONS is a required senior course that has traditionally had an emphasis on building codes with some treatment of land development issues, including environmental considerations. The course was recently revised to include codes and regulations in all civil engineering subdisciplines and work beyond or outside of codes and regulations. This included expansion of the environmental considerations into a sustainable development module. In the Fall of 2002, roughly 20% of the course focused on sustainable development. Class activities included completing a LEED rating of an existing facility. The incorporation of this new content was not considered a compromise in coverage because the course had been designated for revision to better meet course and department objectives by the previous instructor and department. The revisions better complied with the course objective of familiarity with civil engineering codes, regulations, and site development issues. Cognitive learning in the sustainability module covered language development, comprehension and application.

CIVIL ENGINEERING DESIGN AND SYNTHESIS, a required senior level course, is the capstone design course in the civil engineering curriculum. Students working in teams of 3 to 4 undertake real projects submitted by corporate and government sponsors. Presently, alternatives considered for design often include sustainable technologies, such as wetlands, alternative energy sources, or recycling of available materials, and the students are aware that the alternatives are environment-friendly. However, inclusion and consideration of sustainability is project-dependent, being driven by project needs or the client interests, rather than as a fundamental consideration. Our goal is to make sustainability assessment as fundamental to future projects as checking for code compliance. Cognitive learning occurs in these projects through all lower learning levels up through synthesis and is enhanced by learning in the social, affective, and sometimes psychomotor domains.

The highest integration will occur when we obtain faculty buy-in that leads to regular dialogue on sustainability with students both inside and outside the classroom. Sustainability is integrated into all engineering design courses because it is inherently factored into a student's design process. Our bottom-up approach to integration started with a single faculty introducing sustainable engineering into a core course. Progress slowed as key faculty teaching sustainability left. Although new faculty brought an interest in sustainability to the department, program integration slowed in the transition. Faculty transitions could put the growth of sustainability learning in the department at risk. Although such faculty transitions are a weakness, the bottom-up approach does benefit from reduced administrative planning and financial investment.

Small civil engineering departments can benefit from the bottom-up approach. A single faculty teaching ENVIRONMENTAL ISSUES or CIVIL ENGINEERING CODES AND REGULATIONS AT RHIT will contact almost all junior or senior civil engineering majors respectively. Therefore, a single faculty or small number of interested faculty can have an immediate positive impact on students' views of sustainability. The development of multidisciplinary research centers on sustainability and the integration of sustainability throughout a whole engineering curriculum, a top-down approach to integration, have been successfully used at larger institutions to introduce sustainability into the curriculum[7]. However, they often require a significant administrative and financial support.

**Assessment**

The most recent assessment of student attitudes about sustainability occurred in the previously referenced CODES AND REGULATIONS class (Fall 2002). Assessment included assigned student reflection in writing after completing the sustainable development module, followed by open class discussion about how to improve sustainability learning in the department. Many positive unsolicited student comments about the sustainable development module were also made in the end of quarter class evaluation. In a final week curriculum discussion, the class, comprised of all graduating seniors for the 2002-03 academic year, selected sustainable development as the most important topic needing more attention in our curriculum. Comments included:

- "...the sustainability part was a lot of stuff I had never heard of that has a lot of good ideas..."
- "Sustainability engineering has really caught my attention."
- "I was introduced to a lot of new ideas that helped broaden my perspective."
- "The [sustainable development speech on videotape] was GREAT!"
- "It would be nice if sustainability is covered more in depth. This is important. So what about geothermal, green roofs, and a lot of other energy-saving systems? How do they work? How do we use them?"

Positive student response to sustainability infiltration of non-environmental courses was a surprise, particularly the broad positive response. Students perceived to be strongly non-environmental in interest generally liked the ideas nevertheless. The faculty leading discussions often reminded the students that sustainable design and construction is simply a higher level of quality engineering, a step above just following the same old codes and regulations, and an opportunity to put the engineer more in control of the development, thus elevating their leadership of the project, their involvement, and frankly, their fees.

**Final Comments**

The initiative to incorporate sustainability into civil engineering courses and curricula may begin in each department with a single faculty or a small group of faculty, but it must begin. There are resources available to assist faculty and departments as they proceed in this effort. The eventual goal should be broad exposure across the curriculum, within all subdisciplines of civil engineering.

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