AC 2010-1458: TEACHING SUSTAINABILITY AND SUSTAINABLE ENGINEERING PRACTICE IN THE CIVIL ENGINEERING CURRICULUM

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Teaching Sustainability in a Civil Engineering Curriculum

Abstract

The objectives of this paper are to (1) present the approach used to integrate sustainability content into the civil engineering curriculum at the University of ____, (2) assess the effectiveness of the approach, and (3) provide general recommendations to improve the integration of sustainability into the civil engineering curriculum. The approach being implemented at the University of ___ involves brief references to sustainability at the lower levels, targeted modules in junior and senior level courses, and dedicated project-based electives at the senior and introductory graduate level. A sustainability knowledge survey was administered to students at the sophomore, senior, and Masters levels to determine their relative knowledge of terminology, concepts, and practice as it relates to sustainability and civil engineering. The results were analyzed to determine the relative knowledge and depth of understanding of sustainability at the three levels that have been exposed to different levels of sustainability content in the civil engineering curriculum. The results are also synthesized with analysis of student recognition of sustainability in course assignments and previous results assessing effectiveness of a course dedicated to teaching sustainable design. Overall the results showed an increase in sustainability knowledge as the students progressed through the curriculum from the sophomore to senior years. By the end of the curriculum more than 90% of the students surveyed could define sustainability, had heard of LEED® and could list an example of sustainable design in civil engineering practice. But less than 30% could identify a specific example of sustainable design instruction and less than 10% could identify specific elements of sustainable design practice such as LEED® Credit Categories. Overall, the assessment indicated the need to provide more in-depth coverage of sustainability concepts and design in the form of dedicated courses in addition to the continuous coverage in the form of lessons and modules in existing courses. In addition, a need to expose civil engineering students to greater multi-disciplinary courses in sustainability and sustainable design at the lower and upper levels is noted.

Introduction

A Google search of 'sustainability' returns more than 32 million hits, compared to 13 million hits 2 years ago. An incredible amount of information related to the concept is being amassed and at a rapid rate of increase. This degree of change suggests the concept continues to evolve and expand making it challenging to define. One of the most often referenced definitions is the classic statement presented more than two decades ago by the Brundtland Commission[1]:

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

This definition continues to be referenced today and reincarnated in different forms. In civil engineering practice, for example, sustainable development is defined by the American Society of Civil Engineers (ASCE) Board of Direction as:

> "…the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development."

As Mays[2] points out, the concept of sustainability is not new. However, official recognition of the concept in practice has come relatively recently. For example, the ASCE Board of Directors introduced the concept into the ASCE Code of Ethics a little more than a decade ago[3].

Equipping civil engineers at the university level to plan and design sustainable developments, buildings, and processes is also relatively new. Even sanitary and in more recent times environmental engineering, which is a fairly mature civil engineering sub-discipline, focused predominantly in the environmental and economic spheres of sustainability with less emphasis on the social element. Steineman[4] reviewed the history of declarations of the roles and responsibilities of universities to promote sustainable development and traced the calls for action back nearly two decades. She also highlighted the position of universities to help answer the call of the profession. Since the profession (e.g., ASCE) introduced the concept of sustainable design and in turn made a call for increased adherence to its principles and provided guidance for implementation[5], sustainable development and design have been incorporated into engineering education. Educators have developed approaches to introduce sustainable engineering concepts across departments in Colleges of Engineering[6], in environmental engineering[7], in civil engineering[8,9,10], and to address ABET criteria[6]. Sustainable development concepts have also been introduced into international university curricula[11,12]. And very recently implementation of sustainability has been highlighted as a means to realize an important element of the ASCE Body of Knowledge[13].

Although the introduction of sustainability concepts into engineering in general and civil engineering in particular is rapidly occurring, the most effective way to implement it into civil engineering courses and the civil engineering curriculum remains uncertain. For example, the effectiveness of frequently referencing sustainability in civil engineering courses and incorporating lessons or modules into existing courses is largely unknown. Also unknown is how well students retain sustainability concepts and design techniques introduced briefly in previous courses. Another uncertainty is the role of internships and professional practice in supporting the sustainability education of students in civil engineering. Answers to these questions would help shape approaches to effectively integrate sustainability into civil engineering education. This paper presents the approach to incorporating sustainability into the civil engineering curriculum at the University of _____ and assesses the effectiveness of the approach at the sophomore, senior, and Masters level.

Incorporating Sustainability into the Civil Engineering Curriculum

The Department of Civil and Environmental Engineering at the University of ____ has implemented sustainability into their undergraduate curriculum in several ways at multiple levels of the program. The approach has been independently created with minimal coordinated planning by several faculty members that each recognized the need and took action to implement elements into their courses or develop new courses. When taken together it is suspected that the combined effect of the individual efforts is providing a continuous reinforcement of basic terms and concepts, but limitations of the uncoordinated approach are inhibiting deeper understanding of concepts and extension into practice.

The approach provides exposure in the early-to-mid level courses, senior-level technical electives, and the capstone course in the undergraduate program and additional dedicated sustainable design courses at the graduate level (see Figure 1). Specifically, the curriculum provides a brief overview of sustainability terminology and concepts at the freshman level and civil engineering specific content at the senior level. Also at the senior level and graduate level students may also take specialized courses in sustainable design.

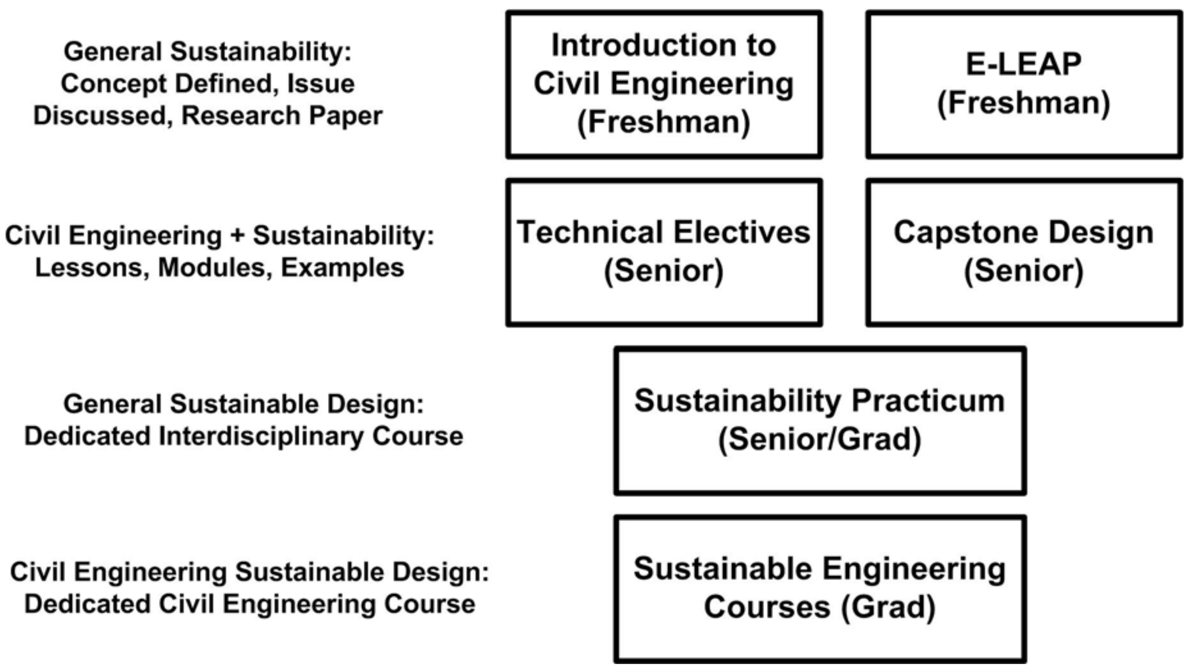

Figure 1. Course flow chart highlighting integration of sustainability concepts and sustainable design in the civil engineering curriculum at the University of _____.

In the freshman year, incoming civil engineering students are introduced to the general concepts and terminology of sustainability. It is discussed in the Introduction to Civil Engineering course as it pertains to the ASCE Code of Ethics. In addition, it is discussed for each sub-discipline of civil engineering (Structures, Geotech, Transportation, Materials, Water Resources, and Environmental) during specific presentations throughout the semester. Overall, the amount of time spent presenting or discussing sustainability concepts is small with specific mention in less than 20% of the class periods (six out of 30). The time devoted to sustainability concepts in each of the six class periods is generally less than 10 minutes. The objective is to provide a definition of the term and concept of sustainability and how it relates to civil engineering practice.

A recent requirement added to the engineering curriculum is the Engineering-LEAP (E-LEAP) program. E-LEAP is a year-long seminar focusing on the theme of community building in American and in global settings, and the ethical standards of engineering. A paper on sustainability is required, but limited class time is dedicated to specific discussion of sustainability. The topic is mentioned throughout the course, but limited reinforcement and lack of assessment of student learning of sustainability concepts likely limits the retention.

Students may elect to take sustainability-oriented courses to meet their general education requirements. However, at this time the sustainability content of general education courses are not known and thus advising cannot easily promote the integration of sustainability into the civil engineering curriculum through this avenue. In the future if the sustainability content of general education courses were known advising to civil engineering students could provide targeted recommendations or perhaps requirements to ensure a selected level of sustainability education. A Sustainability Certificate program is under development for all students at the University of ____, and part of this program will include the designation of courses across the university with substantial sustainability content. This could greatly enhance the ability of civil engineering departments to guide students towards general education requirements that would also promote sustainability education in the civil engineering curriculum and across the University.

At the upper level, students are exposed to sustainability concepts in required civil engineering courses (e.g., Introduction to Environmental Engineering, Introduction to Transportation Engineering, Materials) and senior-level technical electives (e.g., Stormwater Management and Design, Pavement Design). Of these courses the most in depth consideration of sustainability comes in the form of a final project for the Materials course where sustainability concepts are a required element. In the other courses, sustainability is of course mentioned periodically as it relates to course content, but entire lessons are not dedicated to presentation of the concepts, terminology, and engineering practice of sustainability in general. Furthermore, the coverage of sustainability is not reinforced in a systematic way through readings, homework, projects, etc. such that it could be assessed as a learning objective.

Of the upper level courses incorporating lessons or modules, the capstone senior design course has the most encompassing coverage of sustainability. A dedicated lesson on Engineering Sustainability is delivered near the beginning of the semester. The lesson includes coverage on general sustainability concepts including the three spheres of sustainability, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) professional accreditation and project certification programs, and ASCE initiatives and programs in sustainability. In addition to the lesson, sustainability concepts are incorporated into the integrated design project. The project each semester is selected to require an integrated team from several sub-disciplines of civil engineering to coordinate and conduct the design. A specific objective of the integrated team is to address sustainability broadly and also directly related to the design. Most often an individual or a sub-team is tasked with the sustainability objective.

Another element incorporating sustainability in the civil engineering curriculum at the University of ____ is a senior-level technical elective course that was developed four years ago to provide a complete coverage in sustainable design practices[14]. The course is offered once per year and is taught from an interdisciplinary perspective to a multi-disciplinary set of students. The goals of the Sustainability Practicum course are to (1) integrate multiple disciplines into a single course and teach sustainability and sustainable design from a multi-disciplinary perspective and (2) immerse students in real problems and projects and facilitate their development of the ability to create interdisciplinary solutions meeting constraints and the approval of design professionals and stakeholders. Students from civil engineering are engaged with students from any major across the university. In the past, the course has included students from engineering, business, environmental science, geology and geophysics, biology, chemistry, urban planning, communications, philosophy, and architecture. To encourage the broad participation, the course is cross-listed in Geology and Geophysics, Civil and Environmental Engineering, Biology, Environmental Studies, and Urban Planning. In the course, students are introduced to the concepts of sustainability from the global, regional, and local perspectives and the foundation of design and certification (e.g., Leadership in Energy and Environmental Design (LEED®)). Students are divided into multi-discipline teams to complete a project. Projects may cover assessment, analysis, design, outreach, or other means to achieve sustainability. Projects may be broad interdisciplinary or focused on a particular discipline, but addressed from an interdisciplinary perspective. Depending on the projects students may be introduced to a range of sustainable design tools including whole life cost estimating and economic analysis, payback calculations, life-cycle assessment, system dynamics modeling, and water and energy auditing.

Several additional civil engineering specific technical elective options are available in the form of Masters level graduate courses dedicated to sustainable practice in a particular discipline. The two courses most dedicated to a broad coverage of sustainability are Sustainable Urban Water Engineering and Climate Change Science and Engineering. Both are graduate courses but may be taken by advanced undergraduate students with a sufficient GPA. The Sustainable Urban Water Engineering course is a project-based course focused on planning and designing integrated urban water infrastructure systems for long-term sustainability. Students explore the interactions of human activities and urban water systems at neighborhood to regional scales. Topics include LEED®, low-impact development, green infrastructure, rainwater harvesting, permeable pavement, green roofs, planning water supply for climate variability, water conservation, graywater reuse, and wastewater recycle and reuse. The Climate Change Engineering course is a collaborative teaching effort from several universities in the U.S. providing a broad coverage of climate change science and then a specific coverage in the area of carbon capture and storage. Both of these dedicated graduate courses are in the water resource and environmental engineering part of the civil engineering graduate program.

Overall, civil engineering students at the University of ____ are given minor exposure to general sustainability concepts in their freshman and sophomore years in both a discipline-specific and general context. More in-depth coverage within the civil engineering discipline is provided in junior-level courses and senior-level technical electives using isolated lessons and modules. An interdisciplinary opportunity in the form of the Sustainability Practicum provides a unique opportunity for a limited number of students. The capstone course provides most integrated coverage of sustainability required of all civil engineering students. Students may seek additional discipline-specific in-depth coverage of sustainability with entire courses dedicated in the graduate program. Beyond courses, civil engineering students are encouraged to increase their sustainability education, especially as it relates to civil engineering practice, with an incentive to pass the LEED® Green Associate exam and become accredited professionals. The Department of

Civil and Environmental Engineering covers the application and exam fees of any student in one of the department's dedicated sustainability courses that takes and passes the exam.

Analysis and Assessment

As noted above, the approach to incorporate sustainability topics into the University of ____ Civil and Environmental Engineering curriculum is based on a fusion of independently developed elements. To identify areas to improve the effectiveness of the program, an assessment was performed. The assessment was accomplished by analyzing students' grasp of the concepts, terminology, standards, presence in practice, and design techniques at several levels in the program. The assessment has been performed with surveys and analysis of student work in the sophomore level Statics course (Spring 2010), the senior level Sustainability Practicum course (Spring 2009), the senior level Stormwater Management and Design course (Fall 2009), the capstone design course (Fall 2009, Spring 2010) and the graduate Sustainable Urban Water Engineering course (Spring 2010).

Based on survey results from students in the sophomore level Statics course the majority of students (75%, 21 of 28 students) had been introduced to the concept of sustainability. Of those that responded affirmatively, 5 identified the Introduction to Civil Engineering course as the source, 4 identified the E-LEAP course (see Figure 1), while the others identified other courses at the University, sources outside the University, or the current Statics course. More than 50% of those that had been introduced to sustainability had been so in the civil engineering curriculum. However, of the 21 that had been introduced to the concept, only 4 could define sustainability accurately as meeting the needs of the present generation without compromising the needs of the future. A few indicated stewardship of the planet, but most had a very "engineering-oriented" perspective suggesting sustainability is the ability to build structures that last or to extract resources without impacting the environment. Of the entire class, 93% correctly stated sustainability goes beyond the technical aspects of engineering design and of those most could identify a specific factor to consider (e.g., economics, environment, politics, culture). Students were also asked to answer several civil engineering practice specific questions. None had heard of LEED® and only a few could identify an example of sustainability in a civil engineering design, identifying the use of recycled materials. In summary, at the sophomore level the civil engineering curriculum is providing a basic recognition of sustainability, but is minimally contributing to the students' in-depth understanding of sustainability and its place in civil engineering practice.

The sustainability knowledge survey was also administered to the Spring 2010 senior capstone design course very early in the semester before the lesson on sustainability. The survey indicated 21 of 22 students had heard of sustainability. Interestingly the only student that had not heard of sustainability was a transfer student from Mexico. Nearly half of the students identified the Introduction to Civil Engineering course as the first time they had heard of sustainability. The others identified junior level courses, senior technical electives, and work. Almost all indicated they had heard it mentioned in at least one civil engineering course in the current semester. Of the 21 students that had heard of sustainability, 10 could define it accurately in a way that captured the concept of meeting current needs without impacting future generations to meet their needs. All students (even the one that had not heard of sustainability) could provide some semblance of a definition that seemed on the right track. Interesting, of the 21 students only 4 could list the Triple Bottom Line of sustainability. Nearly half of the students had not heard of LEED® and only 2 could list and/or describe the basic elements (Credit Categories, Rating System, Certification, etc.). And similar to the Statics course, only 3 students could identify a specific example of sustainable design in civil engineering practice (and all three had to do with using recycled materials).

In the technical electives courses sustainability is commonly incorporated in the sub-discipline specific content. For example, in the Stormwater Management and Design course three lessons on sustainable stormwater design are presented during the 4th to 6th weeks of the 15-week course. Similar levels or lesser levels of coverage are included in most of the other technical elective courses. Presenting concepts on sustainable design and modified stormwater management objectives for sustainability are clearly introduced, shown in design examples, and then referenced at later points in the semester. The effectiveness of the three lessons in totality was assessed by analyzing the <u>*unprompted*</u> use of the sustainability concepts and sustainable design techniques in the final design projects (all of which should have been heavily influenced by sustainability principles and design techniques). The key aspect of this assessment was the use of sustainability concepts and techniques was not required and was not even mentioned in the design assignment. Of the 9 student teams in the fall 2009 semester, 4 appropriately introduced sustainability concepts in their designs. The application in the design projects suggested a basic understanding of the concept of sustainability and an ability to apply it in civil engineering practice in a sub-discipline specific way (water resources). A follow-up discussion with the professor instructing the course uncovered two possible reasons why the concepts were overlooked by the other teams. First, the teams that did not implement sustainability concepts failed to recognize the linkage of their project to the larger context and thus failed to identify ways to incorporate sustainability into their project. And second, 4 of the 5 teams that did not introduce sustainability concepts did so in part because they were familiar with the practice of stormwater design from their current jobs (at the University of ____ nearly all senior level students are employed in some engineering capacity). The second observation is discouraging in that students were overriding their education of the emerging concepts given their limited internship experiences.

The final level of the sustainability integration assessed was at the advanced undergraduate and graduate level. The survey was administered at the beginning of the first class of the Sustainable Urban Water Engineering graduate course (8 of the 23 students are advanced undergraduates taking the course to get a head start on graduate school as part of the Fastrax program). Similar to senior design, 22 of 23 students had heard of sustainability with the only student providing a negative response being a new graduate student from China. Many of the students listed a range of courses in the civil engineering curriculum that had covered sustainability content. All of the courses shown in the graphic in Figure 1 were mentioned multiple times as a source of sustainability knowledge. Less than 30% of the students had been given specific sustainable design instruction – those that had taken the Stormwater Mangement course and/or the Sustainability Practicum course were the only ones. Of the students that had heard of sustainability nearly all could define it in a way that captured the spirit of meeting current needs without impacting ability of future generations to meet their needs. Approximately half of the class could list the Triple Bottom Line, while most had heard of and could describe to some level

LEEDⓇ. All students that had heard of sustainability could also list at least one civil engineering design example and interestingly they covered a wide range of civil engineering sub-disciplines including materials, transportation, water, and environmental. As a final consideration the responses from the students in this course were more in depth, specific, and with greater detail than the responses to the surveys in the Statics and senior design courses.

Synthesizing the survey results from the individual courses suggests there is a clear progression in sustainability knowledge and capabilities, both in general and specific to civil engineering practice. Figure 2 displays selected survey results for the three assessed levels in the civil engineering curriculum. Knowledge of sustainability is achieved at all three levels through the brief coverage of the concept in the Introduction to Civil Engineering course and E-LEAP for most. The ability to acceptably define sustainability, to list the Triple Bottom Line, and to know of LEEDⓇ is not achieved until the end of the curriculum as shown by the sharp increase in the affirmative response at the advanced undergraduate/entry graduate level. A particular problem noted is the inability to list a civil engineering specific example of sustainable design at the beginning of the senior design course, and the nearly complete lack of instruction in sustainable design practices throughout the curriculum.

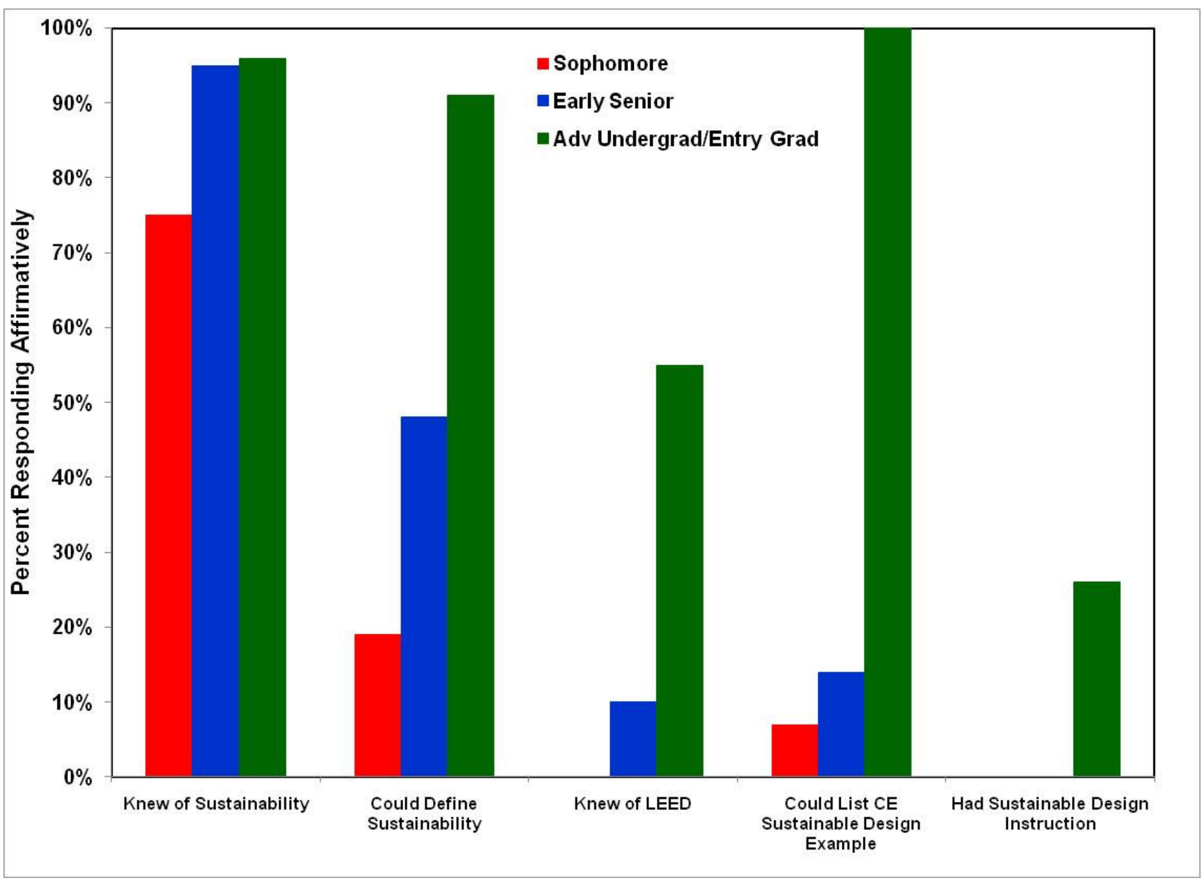

Figure 2. Selected survey results displaying change in sustainability knowledge and capability through the civil engineering curriculum.

Summary and Conclusions

This paper described and assessed the approach to incorporate sustainability concepts and sustainable design instruction into the civil engineering curriculum at the University of ____. The approach provides brief descriptions of sustainability and sustainable design in the freshman and sophomore courses with the potential for additional instruction in general sustainability through general education requirements. Sustainability and sustainable design instruction is also incorporated into junior and senior level required technical courses, the capstone design course, and the senior level technical electives. Opportunities for students to have dedicated sustainable design instruction in specialized technical electives at the senior and entry graduate level are also possible. Overall, the approach has evolved in an uncoordinated manner with independent efforts to incorporate sustainability concepts and instruction into courses at all levels. Only now is the approach being assessed and analyzed for ways to better coordinate the instruction and to be more effective. The limited (one year) assessment described here is the beginning of a process to improve the integration of sustainability concepts and sustainable design practice into the civil engineering curriculum at the University of ____.

The assessment was conducted through sustainability knowledge surveys completed at the sophomore, entry senior, and undergraduate-graduate transition levels. The survey queried student knowledge of sustainability and LEED®, their ability to define key terms and concepts, and their experiences with sustainable design in their courses. In addition, analysis of student assignments and unprompted use of sustainable design concepts were considered.

The results showed a clear increase in sustainability knowledge as the students progressed through the curriculum. The brief instruction provided in the Introduction to Civil Engineering and E-LEAP courses is essentially providing students a vague understanding of the concept but within a year after the instruction they are not able to provide a basic definition of the concept or display an ability to link sustainability to civil engineering through examples or design practice. Students show an increased knowledge of sustainability through repeated description of concepts in the upper level courses, but a large fraction of the students still fail to retain an ability to accurately define a global definition of sustainability. And a large fraction is also unable to show an ability to link sustainability clearly to civil engineering practice. Only after taking specific sustainable design courses in the curriculum are students capable of providing clear definitions and show knowledge of sustainable design in civil engineering practice. Even though students at the end of the curriculum are showing improved knowledge and abilities in sustainable design, they are missing a broader perspective of sustainability.

The results of the assessment suggest students need to be engaged in activities and assignments that require them to achieve a deeper understanding of sustainability and sustainable design at the freshman and sophomore levels. It is important to note that the Introduction to Civil Engineering course at the freshman level describes sustainability and sustainable practice, but does not engage the students in a homework assignment or require some level of accountability for the knowledge. Considering this shortcoming, a possible solution is to provide/require a general sustainability course as a general education requirement at the sophomore year to bridge the gap from initial introduction at the freshman year to the senior level courses. A second recommendation based on the assessment is the need for greater multi-disciplinary interaction in sustainable design. The students in the courses with sustainable design instruction in the civil engineering curriculum are not displaying at a later time (the next semester) an ability to place sustainable civil engineering practice in the larger context of sustainability. Students that have completed a multi-disciplinary course in sustainable design do display this ability. The final recommendation is to incorporate greater sustainable design principles related to civil engineering practice into the senior design course. This is an area that is currently being acted upon with a change being implemented for the Fall 2010 semester.

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