AC 2009-335: MURPHY_ETAL_ASEE_SUSTAINABILITYEDUCATION_ABSTRACT

Cynthia Murphy, University of Texas, Austin

David Allen, University of Texas, Austin

Cliff Davidson, Carnegie Mellon University

H Scott Matthews, Carnegie Mellon University

Chris Hendrickson, Carnegie Mellon University

Braden Allenby, Arizona State University

John Crittenden, Arizona State University

Center for Sustainable Engineering: Sustainability Education Courses in US Engineering Programs

Cynthia Murphy[1]*, David Allen[1]; Braden Allenby[2]; John Crittenden[3]; Cliff Davidson[4]; Chris Hendrickson[4]; Scott Matthews[4]

[1]Center for Energy and Environmental Resources, University of Texas, 10100 Burnet Road, M/C R7100, Austin, Texas 78758

[2]Department of Civil, Environmental and Sustainable Engineering, Arizona State University, P.O. Box 875306 Tempe, Arizona 85287-5306

[3]School Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr., Atlanta, Georgia 30332-0355

[4]Department of Civil and Environmental Engineering, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213

*Corresponding Author: Email – cfmurphy@mail.utexas.edu

Sustainability, broadly defined, is the ability to maintain a particular system. Within the last two decades, it has become increasingly recognized that one of the most critical systems that needs to be maintained from a human perspective is the balance between environmental, economic, and social considerations. The Brundtland Commission report describes this as "meeting the needs of the present generation without compromising the ability of future generations to meet their needs" [1]. Engineering, with its basis in scientific objectivity and focus on problem solving, would appear to be an appropriate home for the study of and development of solutions to issues of sustainability (or lack thereof). A recent study performed by the Center for Sustainable Engineering (CSE), a consortium of the Univ. of Texas at Austin, Arizona State Univ., and Carnegie Mellon Univ. has found that sustainability is an area that many engineering educators are embracing. Indeed, with the caveat that the results of this effort represent a sample and not a full population, it appears that sustainable engineering is becoming a widely accepted practice. More detailed information about this study, including the final report [2] and other resources, can be found at www.csengin.org.

This paper describes some of the educational approaches being employed within US engineering departments to incorporate sustainability concepts into engineering education, with a particular focus on civil, architectural, and environmental engineering. These three programs are considered as a single unit within the study because they represent common groupings at the department level. In evaluating sustainable engineering, these disciplines are of particular interest because they have the potential to play a leadership role: "environment" is one of the three "legs" of sustainability, while civil and architectural engineering represent significant anthropogenic flows of materials and energy and reflect the needs and desires of society.

In the first of a two-step benchmarking process, the administrative heads of 1368 engineering departments (or the equivalent) at 364 US universities and colleges were contacted and asked to complete a questionnaire about the extent to which sustainable engineering was being integrated into their departments. More than 20% of those contacted responded. Within that 20%, more than 80% of all departments and nearly 90% of civil, architectural, and/or environmental engineering departments reported teaching either sustainable engineering focused courses or integrating sustainable engineering material into existing courses.

A second questionnaire was distributed to 327 additional individuals, identified as sustainable engineering champions, in order to capture detailed information about research being conducted and courses being taught in the area of sustainable engineering; only course information will be discussed in this paper. A total of 137 valid responses were received, for a response rate of 43%. Just under half of these 137 were completed by individuals affiliated with civil, architectural, and/or environmental engineering departments. A total of 155 course names were described by the respondents, with detailed information provided for about 80% (125) of these. The 125 courses come from the following disciplines:

- Civil, Architectural, and/or Environmental Engineering, 61 courses
- Mechanical, Aero-, and/or Manufacturing, 22 courses
- General Engineering and Other (including Electrical and Nuclear), 17 courses
- Chemical, Bio-, and/or Materials Engineering, 15 courses
- Industrial, Systems, and/or Sustainable Engineering, 10 courses

The respondents were asked to complete a separate questionnaire for each course that contained at least 4 lecture hours of sustainable engineering content or the equivalent. One set of questions was designed to characterize the course with regard to the course type, the class size and make-up, the maturity of the course, and its structure. A second set addressed the degree to which, and the manner in which, sustainable engineering concepts and interdisciplinary aspects were being incorporated into the course. Finally, the participants were asked to provide names of textbooks, readings, websites, and software used within the course. In some cases this information was entered directly into the questionnaire, in others a syllabus was provided from which these resources were identified.

There appear to be four primary means of incorporating sustainable engineering content and concepts into engineering curricula. Participants were thus asked to characterize each course as belonging to one of the following categories: 1) a dedicated sustainable engineering course, 2) a traditional engineering course into which concepts of sustainability had been incorporated, 3) a sustainable engineering technology course that focuses on technologies predicted to be important in developing sustainable-engineering solutions, such as carbon capture or solar power or 4) a cross- or interdisciplinary course given in conjunction with a non-engineering department. While a stand-alone sustainable engineering course seems to be the most common approach (48%), integrating sustainable engineering concepts into core engineering courses is also a widely used practice (23%). The courses reported on tend to be relatively mature (offered multiple times over the past 5 years) and are characterized by medium-sized classes of predominantly upper division undergraduate and graduate students (Figure 1). Prerequisites for the classes are what would be expected for any engineering elective at the level offered.

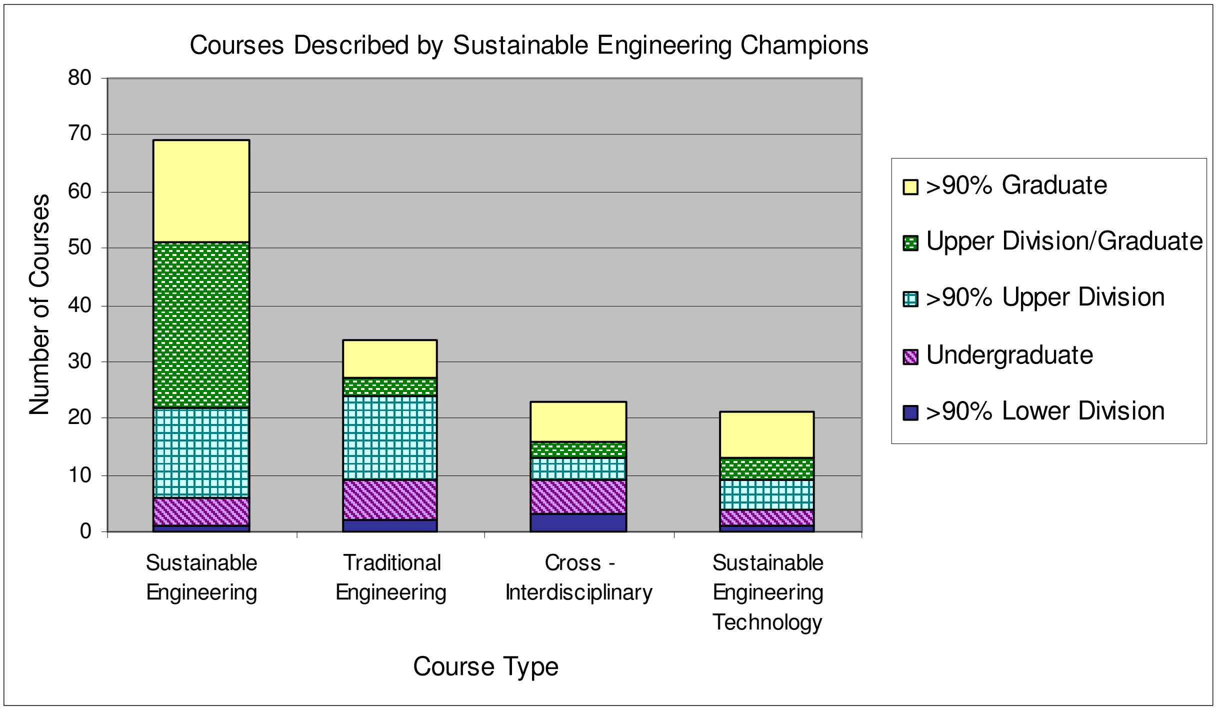

Figure 1. Most students (91%) taking sustainable engineering courses are upper division (juniors and seniors) and graduate students. Undergraduate students (65%) dominate the traditional engineering courses, but most (44%) are upper division. Sustainable engineering technology courses are aimed primarily at the graduate and upper division levels (57%), but 38% of these courses have undergraduate students only.

The materials covered in engineering courses on sustainability were categorized based on a framework that describes four levels of decision-making related to sustainability. The first is referred to as "gate-to-gate." At this level, decisions are made within a single facility or corporation by engineering and/or business units (i.e., site or industry sector specific activities). The second, and next larger system, is what is commonly referred to as "cradle-to-grave." At this level, decisions are made by different entities over the life of a product or sector activity, with activities typically analyzed as sequential events (i.e., life cycle analysis). When interactions between multiple industrial entities or sectors are accounted for, a third decision-making level, "inter-industry" systems (or industrial symbiosis), can be identified. The analysis typically captures spatial as well as temporal effects and scales, although temporal scales may be compressed such that activities are presumed to occur in parallel (i.e., industrial ecology). Finally, decisions at the "extra-industry" systems are considered. These are similar to "inter-industry" systems, but involve multiple stakeholder types, including industry, non-governmental organizations (NGOs), policy makers, consumers, etc. Within these decision-making frameworks, a number of topics can be considered as presented in Table 1.

Table 1. System Boundaries and Topics

System Size	Topics
Gate to Gate	Process design, including material and/or energy reduction
	Material or chemical selection
	Product design for a single phase of a product's life (e.g., design for recycling)
	Pollution prevention
	Media-based (i.e., air, water, solid waste) regulations
Cradle to Grave	Resource availability and economics
	Consumer behavior
	Product utility
	Reuse and recycling options
	Product based legislation (e.g., WEEE) and standards (e.g., ISO 14000)
	Life cycle inventory development
Inter-Industry (Industrial Symbiosis)	Material flow analysis
	By-product synergy
	Eco-industrial development
	Multiple/nested LCA analysis
	Input-output analysis (either physical or economic)
Extra-Industry	Policy development (current and historical)
	Consumption patterns and preferences
	Eco-industrial development
	Multiple/nested LCA analysis
	Input-output analysis (either physical or economic)

Although there is significant diversity in the nature of the courses being taught and the research being conducted, the questionnaire responses reveal several common themes and elements. Participants in the benchmarking activity were asked to indicate whether or not specific topics, as defined by these system boundaries, were addressed within each course. Based on the responses it appears that within the curricula, courses concentrate primarily on smaller systems, particularly those limited to the firm (gate-to-gate or design for environment) or product (cradle to grave or environmental life cycle analysis). Less than half of the courses address larger systems that examine relationships between different firms or industrial sectors (industrial ecology) or between industrial and non-industrial sectors (cultural and social dimensions).

The results for civil, architectural, and/or environmental engineering are compared to courses taught in other engineering disciplines in Figure 2. It is interesting to note that for all but a few topics, courses offered by other engineering disciplines are more likely to address any of these specific topics than are those courses offered through civil, architectural, and/or environmental engineering. The exceptions to this are pollution prevention (56% vs 53%) and media-based regulations (49% vs 28%) at the gate-to-gate decision making level; by-product synergy (18% vs 16%) at the inter-industry level; and multiple or nested LCA (16% vs 14%) at the extra-industry decision-making level. Only the topic "media-based regulations" exhibits a greater than 5% difference. In contrast, all of the topics at the cradle-to-grave decision making level receive more coverage by engineering disciplines other than civil, architectural, and/or environmental engineering, most of them by greater than 5%. At the gate-to-gate level, the topics "materials" and “process-design” also receive more coverage within courses offered by other engineering disciplines.

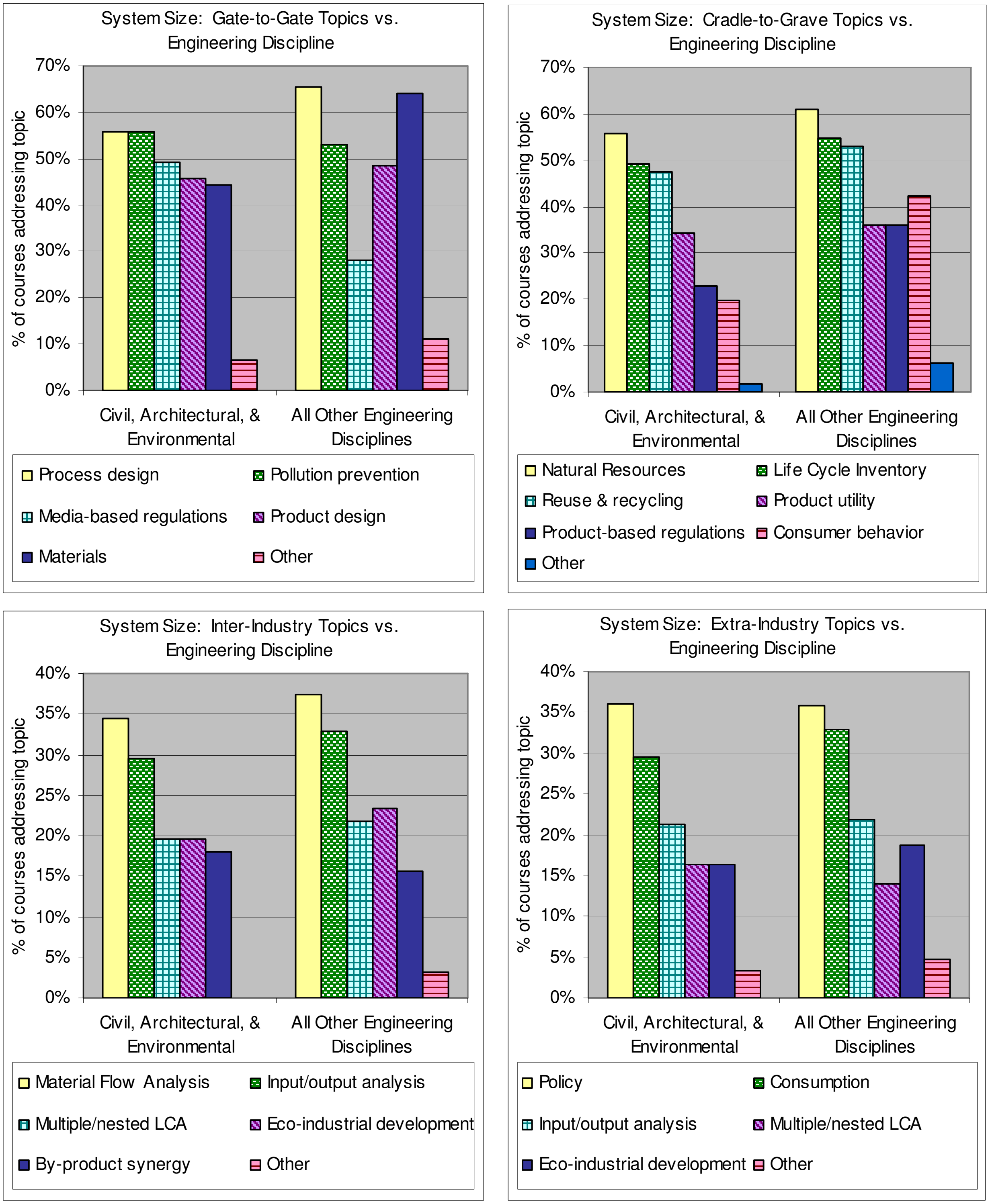

Figure 2. The courses that cover the topics defined in Table 1 are compared, with the percentages indicating the fraction of the courses addressing a general system size that cover

specific topics. For example, about half of the civil, architectural, and/or environmental engineering cover media-based regulations at the gate-to-gate decision level compared to just over one-fourth in other disciplines.

The participants were asked to provide the names of readings and textbooks used in the courses. By examining the abstracts, subject headings and tables of contents of the books and readings, the resources were characterized by a number of themes. These are summarized in Table 2.

Table 2. Themes Addressed in Readings and Books with Top 4 Shaded

	% Times Dominant Theme of Reading or Book		**%Times Addressed to a Notable Degree**	
Theme	**civil, architectural, and/or environmental**	**other engineering disciplines**	**civil, architectural, and/or environmental**	**other engineering disciplines**
Water	20%	0%	32%	3%
Agriculture and Land Use	7%	0%	28%	8%
Systems, Metrics, & Information Mgmt	7%	6%	20%	23%
Urbanism and Urban Systems	7%	1%	16%	3%
Transportation	7%	3%	12%	9%
Design	6%	3%	22%	17%
Building & Construction	5%	1%	9%	6%
Biogeochemical Systems (incl. Ecology)	5%	2%	15%	11%
Humanities (philosophy, ethics, history)	5%	7%	22%	17%
Energy & Power Generation	4%	21%	22%	39%
LCA (Life Cycle Assessment)	4%	13%	11%	22%
Pollution Prevention, Fate & Transport	4%	1%	16%	9%
Policy	4%	3%	27%	24%
Business & Economics	3%	10%	28%	33%
Natural Resources	2%	2%	20%	14%
Industrial Ecology	2%	4%	7%	7%
Industrial Processes	2%	6%	11%	18%
End of Life and Waste Management	1%	8%	13%	16%
Climate Change	1%	3%	8%	12%
Materials	1%	5%	7%	13%
Material Flow Analysis	1%	2%	1%	3%
Human Health	0%	1%	7%	8%

What is clearly striking in this analysis is that there is no overlap in the dominant sustainable engineering themes covered by civil, architectural, and/or environmental engineering as compared to other engineering disciplines and very little overlap in topics covered to a notable degree. At least as reflected in reading selections, civil, architectural, and/or environmental engineering place significant emphasis on water. In chemical, mechanical, industrial and other engineering disciplines, energy is the dominant theme with life cycle assessment second. The exceptions are business and economics and to a lesser degree policy. One interpretation of this is that sustainable engineering is a broad field that lends itself to adaptations that fit the strengths of more traditional engineering disciplinary boundaries. It may however, be illustrative of the need to begin a more formal consideration of just what should be included in a sustainable engineering curriculum. It begs the question, "Is it enough to include economics and policy in the context of environment to qualify it as sustainable engineering?"

The engineering education community is now at a critical juncture. To date, there has been a significant level of "grass-roots" activities and while individual programs are well structured, there is little overall organization at a national level or across engineering disciplines. The next step will be for engineering accreditation bodies to think critically about what should or should not be included in a curriculum into which sustainable engineering has been incorporated. The path forward will require the evolution of a set of community standards. If this fails to happen, the field of sustainable engineering runs the risk of becoming unsustainable itself. The benchmarking effort described here provides a platform that can serve as a resource as standards develop.

Acknowledgment

The U.S. Environmental Protection Agency (EPA), through Grant Agreement X3-83235101, provided funding for this work. Although the research described in this article has been funded in part by the EPA, it has not been subjected to the Agency's peer and policy review and therefore does not necessarily reflect the views of the agency, and no official endorsement should be inferred.

Literature Cited:

1. World Commission on Environment and Development, "Our Common Future," Oxford University Press, Oxford, U.K. (1987).

2. D. Allen; B. Allenby; M. Bridges; J. Crittenden; C. Davidson; C. Hendrickson; S. Matthews; C. Murphy; D. Pijawka, Benchmarking Sustainable Engineering Education: Final Report (2008)