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Implementation of Sustainability Concepts in Environmental Engineering Curriculumns

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John Woolschlager is the founding Chair of a new Department of Civil Engineering that was started at Saint Louis University in the 2009/2010 academic year. Prior to joining Saint Louis University, Dr. Woolschlager was an Associate Professor at Arizona State University and at the University of North Florida. Dr. Woolschlager had been involved in over 3 million-dollars worth of collaborative research and engineering projects. Additionally, he was honored with the Student's Choice Professor Award in 2003/2004 and nominated for the Outstanding Undergraduate Teaching Award in 2004/2005. His research involves developing computer models environmental processes and systems. Some examples of his funded projects include the optimization of hydraulics and water quality in a large-scale urban drinking water system, the optimization of wastewater treatment plants to achieve nutrient reduction, drinking water quality analysis and disinfection chemistry, and regional sustainability issues. Prior to becoming a faculty member, Dr. Woolschlager worked as an engineering consultant in the areas of environmental systems analysis, environmental planning, and water resources engineering for Harza Environmental Services (HES), now part of MWH.

Implementation of Sustainability Concepts in Environmental Engineering Curriculums

Abstract

Environmental engineering programs are historically rooted in sanitary engineering curriculum (water and wastewater engineering) that was typically a sub-specialty of civil engineering. Over time, environmental engineering became more diverse, including topics such as air pollution, groundwater remediation, and hazardous waste management, reflecting the evolving areas of practice in the professional field. More recently, many environmental engineering programs have begun to incorporate sustainability principles into the curriculum, reflecting the need to prepare future engineers to address complex and interdisciplinary issues that challenge our society. The purpose of this paper is to examine how sustainability principles have been integrated into environmental engineering curriculums. A national-level review of all sixty ABET accredited environmental engineering programs reveals that 73% have incorporated sustainability concepts somewhere in their program educational objectives, student outcomes, courses, and/or in program descriptions posted on websites and in catalogs. However, few of these programs exhibited significant curriculum transformation or redesign around sustainability concepts. Furthermore, the majority of programs either did not include any sustainability concepts in their programs (27%) or exhibited a weak level of integration of sustainability concepts in their programs (28%). This lack of significant incorporation of sustainability in environmental engineering programs is surprising, considering that ABET has identified sustainability as an important student outcome. The major challenges that prevent progress in sustainability integration likely include the shifting paradigms around sustainability; rigidity of existing education system; a lack of new methods of teaching; lack of resources or incentives to teach sustainability; no interdisciplinary structure; and the lack of visionary leaders and champions for sustainability.

Background

The field of environmental engineering originally developed as a sub-specialty of civil engineering focused mostly on public health or sanitary engineering starting in the later 1800s to early 1900s. Sanitary engineers played a highly valuable role in our developing urban societies by introducing drinking water and sewage treatment techniques that reduced waterborne diseases from leading causes of death to a rare occurrence. Over time, the environmental engineering field evolved to include other pollution treatment and prevention topics, such as air pollution, groundwater remediation, and hazardous waste management. More recently, many environmental engineering programs have begun to incorporate sustainability principles into the curriculum, reflecting the further evolution of the field of environmental engineering.

The importance of sustainability in education is now recognized by policy-makers worldwide. The United Nations established the need for a reorientation of education to incorporated sustainability principles at the Earth Summit in Rio de Janeiro in 1992[1]. Additionally, the UN identified the need to reform education policies, programs, and practices to address sustainable development issues at the World Summit on Sustainable Development in Johannesburg in 2002[2].

As a result of this ongoing effort by the United Nations to increase sustainability education, the period between 2005 and 2014 has been declared the United Nations Decade of Education for Sustainable Development[3].

The importance of sustainability in engineering education is now recognized in engineering accreditation criteria developed by the Accreditation Board of Engineering and Technology (ABET). The current ABET Criteria for accrediting programs for reviews done during the 2013-2014 cycle[4] includes sustainability in two of the *a-k* student outcomes required for all engineering programs:

> *(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and* ***sustainability****.*
> *(h) the broad education necessary to understand the impact of engineering solutions in a global,* ***economic, environmental, and societal*** *context.*

Beyond ABET, the American Society of Civil Engineers (ASCE) recognizes the importance of sustainability education in their *Body of Knowledge*[5] document developed to define professional development objectives for all civil and environmental engineers. Furthermore, in 1999, the American Society for Engineering Education (ASEE) approved a statement on the need for education in engineering sustainability[6]. The ASEE statement reads: "Engineering students should learn about sustainable development and sustainability in the general education component of the curriculum as they are preparing for the major design experience."

The topic of integrating sustainability in engineering education is reflected in several recent studies[7-12]. Some of these studies focus on the development of sustainability-focused curriculum at specific institutions, while others focus on educational theory of sustainability implementation, such as education outcome development. Few studies have focused on attempting a broad-based assessment of how sustainability is integrated into engineering programs. One study did conduct a broad survey to all academic units that had at least one ABET accredited engineering program[13]. This survey found that a substantial percent of the university faculty respondents indicated that they were teaching courses related to sustainability. However, the survey showed that few faculty indicated teaching cross-disciplinary courses in conjunction with other departments that address economic, political, and social aspects of sustainable engineering. The purpose of this study is to perform a broad-based assessment of how sustainability principles have been integrated into environmental engineering curriculums by conducting a national-level review of all sixty ABET accredited environmental engineering programs.

Before investigating the topic of sustainability, it is very important to define the term. Unfortunately, there is not a clear consensus on the definition of sustainability, or even if the concept adds value to environmental conservation efforts[14]. For example, if we are to develop designs that are sustainable, what are we attempting to sustain? Is it the ecosystem, our industrial productivity, or our consumption-focused lifestyle? While this may seem problematic, some commonly accepted definitions of sustainability have been developed. The World Commission on Environment and Development's (WCED) widely used definition of sustainable development is: "Meeting the needs of the present without compromising the ability of future

generations to meet their own needs[15]." Although the WCED definition is widely accepted, it is difficult to measure. John Elkington developed a concept to measure sustainability called the *triple bottom line,* a method of evaluating sustainability achievement by assessing economic cost, environmental impact, and social acceptability[16]. The *triple bottom line* definition is a more useful definition for assessing the sustainability of an engineering design (or a program that teaches engineering design), since it can be measured and is a more concrete concept than sustainability.

Methodology and Results

All of the sixty environmental engineering programs accredited by ABET were reviewed to evaluate how sustainability is incorporated in their programs of study. Each program website and current catalog was reviewed to see if the word "sustainability" or "sustainable" was used anywhere in the program educational objectives, student learning outcomes, within the core course descriptions, on the program website, or in the current program description in the undergraduate catalog. The incorporation of sustainability in the program was also evaluated by looking for integration of *triple bottom line* concepts – considering economics cost, environmental impact, and social acceptability. If an objective, outcome, course, or program description included consideration of economic, environmental, and social impact, it was also considered to be evidence of sustainability integration. It is recognized that this methodology does not detect cases where sustainability concepts are included in a course, but are not expressed in the course description.

The results of the program review are shown in Table 1. Out of the sixty ABET accredited environmental engineering programs, fifteen programs (25%) reflected sustainability in their educational objectives, eighteen programs (30%) incorporated sustainability in their student outcomes, sixteen programs (27%) had at least one course that reflected sustainability, and nineteen programs (32%) incorporated sustainability somewhere on their website or in the program catalog. However, only four programs (7%) incorporated sustainability concepts in all of these categories (objectives, outcomes, courses and website/catalog), which were classified as

Table 1. Results of Program Review

Review area	Number of Programs	Percent of Programs
Sustainability in program educational objectives	15	25%
Sustainability in student outcomes	18	30%
Sustainability in one or more courses	16	27%
Sustainability cited on website	19	32%
Strong sustainability: All of the above	4	7%
No sustainability: None of the above	16	27%
Weak sustainability*	17	28%

*Only included sustainability in "ABET" student outcome and/or in a website citation.

programs with *strong* integration of sustainability in this study. Sixteen programs (27%) did not reflect sustainability in any category reviewed, which were classified as programs with *no* sustainability incorporation in this study. Seventeen programs (28%) only posted the ABET student outcomes verbatim and/or mentioned sustainability very briefly on their websites/catalogs. These programs were considered *weak* in sustainability integration in this study. Programs not included in the *strong*, *weak*, or *no* sustainability integration were classified as *moderate* sustainability integration in this study. Figure 1 shows the distribution of programs classified as *strong*, *moderate*, *weak*, or *no (none)* in sustainability integration by this study.

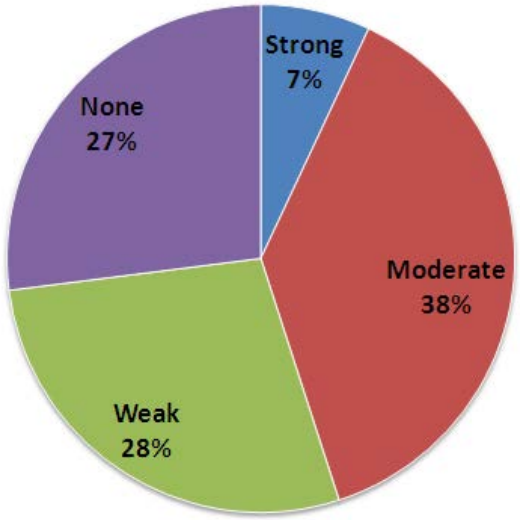

Figure 1. Level of sustainability integration based on program classification metrics used in this study.

One of the primary motivations to perform this review was to examine how environmental engineering programs integrate sustainability in program educational objectives, student outcomes, in courses, and in their program descriptions posted on websites and catalogs. The following sections address each of these categories in detail.

How is sustainability included in program educational objectives?

Among the sixty programs reviewed in the survey, all but six posted program educational objectives on their website and/or in the catalog. This review found that among the fifty-four programs that had posted objectives, only fifteen programs explicitly referenced sustainability concepts within their program educational objectives, or 25% of all programs. Table 2 includes all of the objective statements found in this review that included sustainability concepts. Examining these objectives, the majority express the idea that graduates must consider issues beyond technical considerations, including issues of economics, social, and environmental impacts (the triple bottom line). Some of the program educational objective statements simply add the word “sustainability” or “sustainable” to a list of considerations that should be included

Table 2. Program educational objectives that include sustainability concepts.

University	Program Educational Objectives (Graduates will…)
Colorado State	manage multi-faceted and multi-disciplinary projects with significant legal, ethical, regulatory, social, environmental, and economic considerations using a broad systems perspective.
Georgia Tech	demonstrate understanding of global, societal, environmental, and sustainability issues related to environmental engineering.
MIT	address the complexities of real life environmental engineering problems and be able to formulate solutions that are technically sound, economically feasible, and sustainable.
Michigan Tech	function as productive members of the profession and society with an understanding of the social, ethical, environmental, economic and global ramifications of their work…
Montana Tech	have an ability to design a system, component, or process to meet desired needs within realistic constrains; such as, economic, environmental, social, political, ethnical, health and safety, manufacturability, and sustainability.
Northwestern	play key roles in the analysis of the behavior of complex natural and engineered environmental systems and design infrastructure in a sustainable way to meet societal needs.
Pennsylvania State*	effectively work in and lead interdisciplinary teams needed to design sustainable transportation, water, energy, environmental, and structural infrastructure.
Portland State	have an understanding of contemporary issues relevant to environmental engineering in a context that includes the long-term sustainability and well-being of the community.
Stevens Institute of Technology	demonstrate exemplary sensitivity to social factors including the historical, legal, political, policy, economic, ethical, and public relations aspects of environmental problems. address the wider aspects of environmental problems such as sustainability, design for the environment, pollution prevention, and industrial ecology.
Georgia	achieve a high level of expertise to create design solutions for environmental problems that require integration of environmental and human health constraints compatible with economic growth, sustainable development and ethical standards.
New Hampshire	have demonstrated the ability to evaluate and synthesize data with sound engineering principles, methodologies, and the latest technology into creative, sustainable, safe and economical engineering solutions… have demonstrated in-depth knowledge within environmental engineering and an awareness of potential social, economic, political, and environmental impacts of engineering practices.
Vermont	consider the social, economic, and environmental aspects as part of the engineering solution and problem definition.
Wisconsin-Platteville	have the ability to evaluate projects from a holistic perspective including some or all of the following: sustainability, environmental impacts, ethics, aesthetics, politics, historical perspectives, social impacts, technical needs, and costs.
Wilkes	have technical knowledge for practice in key areas of environmental engineering such as…and (d) resource conservation and sustainability.

*Counts for two accredited programs – University Park and Harrisburg

in a graduate's skill set, which are much less transformational than objectives that express more details about the skill set needed to achieve sustainable design by the program's graduates.

How is sustainability incorporated in student outcomes?

As noted in Table 1, among the sixty programs reviewed, eighteen included sustainability concepts in their student outcomes, or 30% of all programs. The vast majority of programs that post their student outcomes copy the ABET outcomes verbatim. As noted previously, the current ABET Criteria for Accrediting Programs for reviews done during the 2013-2014 cycle, includes sustainability in two of the *a-k* student outcomes required for all engineering programs:

> *(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and* ***sustainability****.*
> *(h) the broad education necessary to understand the impact of engineering solutions in a global,* ***economic, environmental, and societal*** *context.*

Programs that posted student outcomes other that the ones included in the ABET criteria often included concepts that are very close to the ones provided in ABET. This is not surprising, since programs are required to demonstrate the achievement of ABET student outcomes. However, several programs did appear to lose the concept of sustainability in their translation of the ABET student outcomes. It is important to note that among the forty-two programs not including sustainability in their outcomes, twenty-six did not post any student outcomes on their website or catalog. Since most programs use ABET student outcomes verbatim, we can assume that sustainability concepts would be included in most program outcomes in some form, even though the evidence was not visible for twenty-six programs reviewed in this study.

How is sustainability incorporated in courses?

Among the sixty programs reviewed in the survey, all had course descriptions posted on their website and/or in their catalog. This review found sixteen explicitly referenced the word sustainability or sustainability concepts in one or more course descriptions, or 27% of all programs. The typical method for incorporating sustainability concepts into courses is to add the word or concept of sustainability in a course that is typically included in traditional environmental engineering programs, such as Introduction to Environmental Engineering, Freshmen Engineering, or Senor Design or Capstone Design. Below is one example of this method of sustainability integration taken from one of the programs reviewed:

> ***Civil and Environmental Engineering Design:*** *Capstone design experience. Fundamental principles in various areas of civil and environmental engineering applied to open-ended design projects. Economics, safety, reliability, environmental,* ***sustainability****, ethical and social considerations.*

However, seven programs did develop transformational courses designed or redesigned around sustainability concepts that are very different from courses typically found in environmental engineering curriculums. Table 3 includes a complete list of these transformational courses and

identifies the institution where they were developed. These courses vary from courses that are completely devoted to sustainability to ones that combine sustainability concepts with a traditional subject in an innovative way.

Table 3. Courses exhibiting transformational sustainability integration.

Engineering for a Sustainable Society: Case studies of contemporary environmental issues including pollutant distribution in natural systems, air quality, hazardous waste management, and sustainable development. Emphasis is on the application of math, physics, and engineering sciences to solve energy and mass balances in environmental sciences. Introduces students to the basic chemistry, ecology, biology, ethics, and environmental legislation relevant to the particular environmental problem. (Cornell)
Sustainability in Engineering: Sustainable practices are defined and green engineering principles are directed towards engineering design. Life cycle analyses are used to assess environmental, economic, and societal impacts to evaluate material choices, construction practices, water and waste treatment practices, transportation infrastructure, policy and planning, agricultural practices, and energy generation and consumption. (Florida Gulf Coast)
Sustainable Environmental Quality Management: This course will introduce sustainable development concepts with respect to environmental issues. Discussion of global warming, green house gases, green engineering, clean manufacturing, cradle to cradle approach, browns field development, sustainable management of energy and natural resources. (Montana Tech)
Sustainability – Issues and Action: Near and Far Exploration of the issues that motivate the design and engineering of sustainable resource use and development. (Northwestern)
Introduction to Sustainable Design: Theories and principles employed in sustainable design are introduced and employed in various contexts. Analyses of engineering systems will be performed both analytically and quantitatively. Principles will be employed in problem solving as well as fundamental design efforts. (South Dakota School of Mines and Technology)
Sustainability Practicum: Engineering policy dimensions of sustainability. Topics include: (1) definitions and concepts of "sustainability," (2) introduction to climate change science and policy, and (3) relevant analytical tools such as life cycle assessment and carbon footprint analysis. Student teams will conduct studies that integrate environmental, economic, and social concerns in an engineering context, with a strong emphasis on oral and written communications. (State University of New York at Buffalo)
Introduction to Environmental Engineering and Sustainability: An introduction to what is meant by a sustainable economy and society, and how that relates to current conditions in the United States and the world. Emphasis is placed on the key topics such as energy, water, natural resources, transportation, food production, materials use and processing, and waste handling. (Georgia)

How is sustainability cited on websites?

This review found that among the sixty programs that had posted courses, nineteen programs, or 32%, explicitly referenced the word sustainability or sustainability concepts on their website or in the program description in the catalog (beyond citations in the objectives and outcomes). However, there was considerable variability in the amount of emphasis on sustainability expressed on websites and in catalogs. Some programs merely added the word “sustainability” or “sustainable” in statements that would stand alone without the mention of sustainability.

However, other websites exhibited evidence of a transformational incorporation of sustainability, including extensive discourse about sustainability in program mission statements, program descriptions, research, etc. Programs that merely mentioned sustainability in passing were classified as *weak* in sustainability incorporation in this study, even if they posted the standard ABET outcomes that include sustainability concepts. Programs that exhibited more content related to sustainability incorporation were classified as *moderate* or *strong* in sustainability integration in this study, especially those that included some sustainability concepts in program educational outcomes and/or in courses.

Examination of programs with strong and/or transformational sustainability integration.

Only four programs incorporated sustainability concepts in all categories reviewed (objectives, outcomes, courses, and website/catalog). These programs were classified as having *strong* integration of sustainability in this study. The environmental engineering programs classified as having strong integration of sustainability include: MIT, Georgia Tech, Michigan Tech, and the University of Georgia. It should be noted that MIT and the University of Georgia did not explicitly post student outcomes. However, since these programs exhibited substantial sustainability integration in all other areas, and sustainability is included in the current ABET outcomes, these programs were classified as having *strong* sustainability integration (the underlying assumption is that these programs are very likely to use the ABET outcomes verbatim for program assessment).

Before examining these four *strong* programs, it is important to discuss the concept of whether sustainability was merely added on top of an existing environmental engineering program or course or if there was evidence of transformational change made around the concepts of sustainability. Sterling[17] developed the concept of classifying program change into three categories: bolted-on, built-in, and redesign. In this study "bolted-on" denotes that sustainability had limited integration in the program. For example, sustainability could be "bolted-on" to a curriculum by adding the word "sustainability" to a program educational objective or in a course description. "Built-in" indicates that sustainability is identified as a goal of the program and some effort has been made to integrate sustainability concepts and methods into the existing curriculum in the program. "Redesign" signifies that sustainability is a central element of the program goals and significant effort has been made to rethink and redesign the program to completely integrate sustainability into the curriculum at all levels, including incorporation of sustainability in mission statements, program educational objectives, student outcomes, courses, and have significant emphasis of sustainability on the program website and catalog. It is important to note that because a program was classified as having "strong" sustainability integration in this study does not automatically indicate that the program reached the level of "redesign" using Sterling's classification of program transformation.

Among the four programs classified as having *strong* sustainability integration, only MIT and the University of Georgia exhibiting evidence of having redesigned its programs around sustainability according to Sterling's classification system. However, several programs reviewed in this study had made significant transformational change that exceeded Sterling's "bolted-on" category. Examples of programs showing significant redesign beyond the "typical" environmental engineering program include: Columbia, Cornell, Northwestern, and South

Dakota School of Mines. These programs are good examples of how integration of sustainability can go beyond merely "bolting on" the concept to an existing environmental engineering program.

Discussion

The result of this study reveals that a significant number of programs are using the word "sustainability" or "sustainable" in the program educational objectives, student outcomes, in courses, and on their websites. However, uses of these words often do not translate into a transformational curriculum redesign resulting in programs that are much different than that of "traditional" environmental engineering programs. This lack of significant incorporation of sustainability in environmental engineering programs is surprising, considering that ABET has identified sustainability as an important student outcome.

It is important to understand the reasons for the slow pace of sustainability integration in environmental engineering programs. In a detailed study of sustainability implementation at seven universities, *barriers* and *drivers* for sustainability integration were identified[18]:

Barriers:

- *The freedom of individual faculty members*
- *Incentive structure (salaries, promotions, and granting of tenure)*
- *Lack of desire to change*
- *Lack of pressure from society*

Drivers:

- *Visionary leadership*
- *Sustainability champions*
- *Presence of interdisciplinary groups*
- *Size (large universities of more than 10,000-12,000 students often find that the complexity of the organization reduces the possibility of rapid transformation)*
- *The existence of a coordination unit or project for the sustainability transformation may also be important, as it keeps the process of change alive and helps distribute responsibility for the different activities*

Another study of the integration of sustainability in engineering education summarized the challenges identified from three workshops on "Integrating Sustainability into Engineering: Design Principles and Tools to Expand your Educative Capacity" held in 2010 and 2011[19]. The major challenges identified in this workshop included 1) shifting paradigms around sustainability; 2) rigidity of existing education system; 3) lack of new methods of teaching; and 4) lack of resources to teach sustainability.

Conclusions

The purpose of this study is to examine how sustainability principles have been integrated into environmental engineering curriculums. A national-level review of all sixty ABET accredited environmental engineering programs reveals that 73% have incorporated sustainability concepts

somewhere in their program educational objectives, student outcomes, courses, and/or in program descriptions posted on websites and in catalogs. The majority of programs either did not include any sustainability concepts in their programs (27%) or exhibited a weak level of integration of sustainability concepts in their programs (28%). Furthermore, programs that did integrate sustainability concepts often did not translate into a transformational curriculum redesign resulting in programs that are much different than that of "traditional" environmental engineering programs. The major challenges that prevent progress in this area likely include the shifting paradigms around sustainability; rigidity of existing education system; a lack of new methods of teaching; lack of resources or incentives to teach sustainability; no interdisciplinary structure; and the lack of visionary leaders and champions for sustainability.

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