AC 2010-1802: INTEGRATING SUSTAINABILITY INTO COURSES ACROSS THE ENGINEERING CURRICULUM: A FACULTY WORKSHOP MODEL

Stephen Hoffmann, Purdue University, West Lafayette

Inez Hua, Purdue University

Ernest Blatchley, Purdue University

Loring Nies, Purdue University

Integrating Sustainability into Courses Across the Engineering Curriculum: A Faculty Workshop Model

Abstract:

The incorporation of the concepts of sustainability into all engineering projects will be a critical challenge for future engineers. All projects, not simply those that are obviously environmental in scope, are subject to material, energy, and natural resource constraints, and all have an impact on the interactions between the human and natural worlds. To help students understand these needs, faculty at Purdue University have begun to incorporate the concept of "normalized sustainability": the idea that sustainability concerns are *normal* engineering design criteria, on the same level as more traditional constraints, such as cost, reliability, and performance.

This approach requires a cross-cutting coverage of sustainability and environmental issues. They can not simply be presented in one "specialized" course, but instead need to permeate courses throughout the curriculum and at all levels. To facilitate the incorporation of environmental and sustainability concepts into a variety of courses, we held a two-day faculty workshop during the summer of 2009. Participants learned important concepts, discussed appropriate pedagogical techniques and locations, and were able to share ideas of how to infuse sustainability into examples, case studies, problem sets, and choices of material coverage. More than twenty-five faculty and staff from nine disciplines of engineering participated. These participants have since begun to work on specific modules to apply to their courses during the 2009-10 school year. This paper presents the structure of the workshop, the main conclusions and ideas from the workshop, and examples and assessment of ways that sustainability concepts can be seamlessly inserted into courses so as to further the goals of normalized sustainability.

Introduction:

The broad popular concept of sustainability has grown from its roots in the United Nations' "Brundtland Commission" on sustainable development over two decades ago, which provided the classical definition of "meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs."[1] Subsequent formulations of sustainability in different contexts have diverged from the initial Brundtland wording, but the basic themes of intergenerational equity and long-term planning, often cast in terms of renewability, have generally remained as core concepts. The introduction of the "triple bottom line" of social, and environmental, and economic considerations[2], and the related "three P's" of sustainability — people, planet, and prosperity — demonstrate the broadening of sustainability thinking. A true sustainable approach to problem solving requires multidisciplinarity and wide-ranging expertise, and an expansive and all-inclusive process of drawing the boundaries of a problem.

Sustainable engineering and design applies this long-term, system-wide, and complex thinking structure to the traditional realms of engineers. As a first approximation, the concept translates to engineering strategies that explicitly recognize non-infinite resource availability, environmental and ecological system disruption, population growth pressures, and energy renewability. But the broader context of sustainability requires engineers, and by extension engineering students, to

move beyond traditional technical expertise, and incorporate complex aspects of political, social, economic, and environmental systems into engineering design.

Within this broad framework, sustainability clearly moves beyond environmental engineering and becomes a concern for all disciplines of engineering. Several professional disciplinary societies have recognized the importance of sustainability or sustainable development to their field by including them in their Codes of Ethics or similar policy statements. The American Society of Civil Engineers includes in the first "fundamental canon" of the Code of Ethics that engineers "shall strive to comply with the principles of sustainable development"[3]; the American Institute of Chemical Engineers includes "protect the environment" among the "paramount duties" of engineers[4]; the Code of Ethics of the American Society of Mechanical Engineers instructs members to "consider environmental impact and sustainable development"[5] in all projects; and the National Society of Professional Engineers lists as a "professional obligation" the responsibility to "adhere to the principles of sustainable development in order to protect the environment for future generations."[6] ABET has translated these professional responsibilities into accreditation outcome criteria of engineering education programs: sustainability is included in at least two Criterion #3 outcomes: 3(c) cites "sustainability" as a design constraint that students should be able to address, and 3(h) stresses the importance of a broad education that will allow engineers to place solutions in societal context, an important aspect of sustainable engineering.[7]

But even though issues of sustainability are widely recognized as a critical component of good engineering design, few undergraduate courses at Purdue explicitly address or include important sustainability concepts, and most courses that do are in an environmental engineering context. Finding a remedy to this situation is the primary goal of the work described in this paper. A central theme of our approach to fully integrate sustainability into engineering across the college is the idea of "normalized sustainability:" that sustainability concerns are fundamental, or normal, parts of all engineering practice and engineering design.[8] Therefore, we sought to work with faculty teaching courses that are not immediately identifiable as sustainable engineering. We believe that incorporation of normalized sustainability into the broad college curriculum is hampered by uncertainty among faculty about how best to select and frame sustainability concepts within their field, and to some extent, by an uncertainty about content knowledge.

The workshop described in this paper sought to provide faculty with knowledge, ideas, and support that would help them overcome these barriers, and place sustainability concepts, in context of their discipline, into a variety of courses throughout the College of Engineering. This paper describes the workshop philosophy, material, organization, and initial assessment of success. The actual incorporation of sustainability concepts into courses, detailed description of the learning objectives and activities added to courses, and the full assessment of student experiences and outcomes is beyond the scope of this paper.

Planning and Organization of the Workshop:

The workshop, titled "Integrating Sustainability Concepts into the Engineering Curriculum at Purdue," took place over a two-day period in July 2009. Approximately 25 faculty members and teaching staff attended for the entire workshop, representing nine engineering disciplines.

Consistent with the ideas of normalized sustainability, the focus was on a teaching approach that would integrate sustainability into existing disciplinary courses. The faculty workshop model was inspired by the work of Chase and Rowland[9], notably the "Ponderosa Project" at Northern Arizona University and the "Piedmont Project" at Emory University (two early sustainability-across-the-curriculum faculty workshop groups; both, however, were campus-wide and did not stress sustainable *engineering*), and by the summer workshops of the Center for Sustainable Engineering[10]. A key characteristic of the workshop was the breadth of the courses: faculty were not developing sustainability-themed courses, they were developing modules or exercises with sustainability themes to add to existing courses in their departments. In this way, students see sustainability as an integral part of the core curriculum, rather than as an added "special interest" or optional course.

The workshop had two primary identified goals:

1) to provide faculty members with resources and information necessary to tie sustainability concepts, questions, and problems into their engineering courses; and
2) to assist faculty in the development of a single course module, activity, or assignment that can be inserted into a course in the 2009-2010 school year.

Faculty from all disciplines who teach all courses were welcomed, but particular effort was made to recruit and involve people involved in three specific types of courses:

1) introductory classes, including college-wide "First Year Engineering" courses and disciplinary introductory or introductory design courses;
2) engineering fundamentals courses, especially those related to materials, which could address the source, lifecycle, and energy requirements of manufacture, manipulation, recycling and disposal of materials in addition to the current focus on material properties;
3) design courses, including capstone or senior design projects: these are the places where skills learned through the curriculum are integrated and creativity and problem solving are center-stage. Design is, by definition, systematic (students are no longer reductively looking at only one part, but instead are concentrating on the whole), a hallmark of sustainable engineering.

The workshop itself was organized into three sessions, each approximately a half-day long, based on a progression of themes:

- the first session served primarily for inspiration and information, and provided the *context* of sustainability and its relationship to engineering and environmental issues;
- the second session centered on pedagogy and classroom ideas, and presented *content* and tools that could be added to engineering courses to address sustainability;
- the third and final session encouraged *concrete* plans for incorporation into courses or broader curricula; participants were asked to brainstorm, share, and offer constructive critiques to initial ideas of a course activity or module that they would add to a course.

Each session was organized around a mix of activities: brief presentations from facilitators and expert guests, examples and case studies of ways that sustainability has already been introduced into courses at our university and others; discussion questions and small groups to allow participants to develop their personal understanding of how sustainability fit with their courses;

and individual time and space to allow participants to form initial plans for their own personal module and course. An outline of the specific activities in each session is shown in Table 1.

Table 1: Workshop Sessions and Schedule

*Session I: The **Context** of Sustainable Engineering:*
- — presentation: what is sustainable engineering?
- — panel discussion: aspects and examples of sustainable (and unsustainable) systems in engineering
- — curricular example: bringing together design and sustainability
- — group discussion: necessary aspects of sustainable engineering at Purdue

*Session II: **Content** Ideas for Sustainability in the Disciplines:*
- — presentation: classroom tools and resources: Center for Sustainable Engineering online database, annotated bibliography of sustainable engineering education, easily available (online) tools for sustainability analysis, including life cycle analysis.
- — group discussion: sustainability in each discipline and each discipline's curricular structure (conversations in disciplinary groups)
- — curricular example: sustainable engineering and campus operations: experiences and opportunities for courses to interact with the campus Physical Facilities offices.

*Session III: **Concrete** Plans for What to Do in the Classroom:*
- — group discussion: presentations of course module ideas, with suggestions and constructive critiques from the group
- — presentation: funding opportunities in sustainable engineering education and curricular material development
- — group discussion: developing a broad vision for sustainability in the curriculum across the College: what does the College need to do?

Content of the Workshop Sessions:

A major part of the workshop involved exposing the participants to current thinking, issues, and concepts of sustainability and engineering. In choosing items for inclusion from this broad topic, the workshop organizers made effort to include concepts that would be flexible and widely applicable to different types of engineering courses.

The topics related to sustainable engineering included in the workshop can be categorized into five broad areas:

1) *Systems thinking:* presenters stressed to participants the importance of thinking in systems and recognition of connectivity between different sub-systems. This was used as a primary tie between sustainability and engineering design, and participants were encouraged to ask students to consider how design decisions and design analysis could affect systems and processes removed from the immediate design problem. Expanding the sphere of analysis and boundaries of impact and responsibility within an engineering project, and therefore explicitly considering how the project relates to larger

environmental and social systems, now and into the future, is a hallmark of sustainable engineering.

2) *Major environmental issues:* An early workshop session concentrated on framing current global environmental issues and threats, with particular attention to how engineering interacts with the environment. Topics included water resource issues (quality and quantity), land use issues, atmospheric pollution, human health, and climate change. We believe that an awareness of the impacts of engineering and industrial systems on environmental and social systems is a key prerequisite for students to take seriously their responsibilities toward sustainable engineering.

3) *Energy concepts and resource awareness:* Another early session concentrated on the current global energy system and energy availability, alternative energy and its impacts, energy efficiency of design, and design considerations for a products and processes that may need to work in an energy-limited future. The link between energy and sustainable engineering is a clear one, and one that can be applied easily to all disciplines of engineering. Our workshop concentrated on energy resources, but similar discussions of other raw natural resources would also have been useful and appropriate.

4) *Analysis of the impacts and life cycle of engineering materials:* The consideration of the impact of materials throughout their entire life cycle (sourcing, production, use, recycling, reuse, disposal, etc.) is an easy and obvious link for students to understand between engineering and broader systems. A workshop session presented several tools and approaches of life cycle analysis (LCA) of materials ways that LCA of economic systems can show unexpected but important interconnectivity.

5) *Social and political impacts of design:* A common theme throughout several discussions was the broad ethics and societal impacts of international development and current development models, the need for public engagement in engineering solutions, and the unintended societal and cultural impacts of large engineering projects. This discussion ties neatly into the sustainability concept of the "triple bottom line," and it is one that engineering faculty are often ill-prepared to bring into the engineering classroom.

Results from the Workshop:

The first metric of the success of the workshop model was the extent of participation from the various engineering disciplines (Table 2) and the breadth of types of courses that will have or have had sustainable engineering modules and concepts added (Table 3). This marked an important first step toward opening a wide conversation among the engineering faculty on the importance of sustainability and the ways that it can be added to the already full curriculum. In fact, almost half of the workshop evaluation forms, in an unprompted "additional comments" section, noted an appreciation that the workshop had started the broad conversation about sustainability in the College. The fact that the workshop group crossed disciplinary boundaries was critical to this success, and to the creation of a core group of faculty interested in sustainability.

Table 2: Characteristics of Workshop Participants:

Discipline (number of participants)*
Aeronautics and Astronautics (3)
Agricultural and Biological Engr. (3)
Civil Engineering (4)
Chemical Engineering (1)
Construction Engr. & Management (1)
Electrical and Computer Engineering (2)
Environmental and Ecological Engr. (7)
First-Year Engr. / Engineering Education (7)
Materials Engineering (1)
Mechanical Engineering (4)

Title (number)
Professor (8)
Associate Professor (4)
Assistant Professor (9)
Instructional Staff / Post-doc (5)

Primary Teaching Responsibility
First-Year Engineering (5)
Engineering Fundamentals (4)
Senior / upper-level design (11)
Varies / more than one of above (4)
No current teaching responsibility (2)

Gender: 65% men, 35% women.

* - some participants hold appointments and teaching responsibilities in multiple disciplines.

Table 3: Titles of selected courses at Purdue with sustainability modules added because of the workshop:

Introduction to Architectural Engineering
Advanced Energy Solutions
Thermodynamics
Digital Systems Senior Design
Statistics for Engineers
Construction Management Senior Design
Separations Processes
Introduction to Mechanical Engineering Design
Transforming Ideas to Innovation (First-Year Engineering Design Course)

Both in small and large group discussions, three main themes and points of consensus emerged. First, the workshop participants expressed general agreement for the critical need for broad sustainability education in the engineering curriculum. This consensus likely has an aspect of selection bias to it (workshop participation was voluntary, so it may be inferred that all participants were inclined to understand the need of sustainability). Second, it became clear that the participants embraced the notion of normalized sustainability and the need for all engineering students to experience sustainability concerns in their education. This led to a recurring analogy in the comments: for sustainability, like traditional topics such as thermodynamics, there is a need for some engineers to know a lot, but there is also a need for all engineers to know some. Sustainability is not a topic or concern that can be left simply to a small number of disciplinary engineers. Third, most faculty agreed that, within their home department's curriculum, design courses and design experiences were a particularly effective and important place for the integration of sustainability ideas.

As a preliminary assessment of the workshop, participants were asked to rate their self-perceptions of abilities to effectively teach sustainable engineering, on a scale of 1 to 5, at the beginning and the end of the two-day workshop period (Table 4). Statistically significant increases were observed for four of the five questions, relating to the participants' abilities to explain why sustainability is a core concept of engineering, to locate sustainability content resources, to identify pedagogical tools and teaching resources, and to understand the importance of sustainability to other engineering disciplines.

Table 4: Participant self-perception of abilities to teach sustainable engineering, before and after the workshop

Self-perception statement	before	after
"I am **adept at locating content resources** related to teaching environmental sustainability."	3.1	3.8
"I can explain why sustainability is a **core concept** of engineering."	3.3	4.5
"I know how to **identify and use tools** related to teaching sustainability."	2.8	3.9
"I am aware of **how engineering disciplines other than my own include sustainability** in their curricula."	2.6	3.6
"I am confident that I can **identify effective ways** to include environmental sustainability concepts into the courses that I teach."	3.7	4.0

Participants were asked to rate their level of agreement with the statement on a scale of 1-5:
1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree

Statistical method notes: Data listed in the table reflect results from 14 participants with paired *before* and *after* responses. Significant differences between *before* and *after* responses for the first four questions were observed using a paired *t*-test at the 95% confidence level. A total of 25 *before* surveys were collected, but for 11 of the participants, *after* surveys were not available. Comparison of means tests between the "paired" set of 14 *before* surveys and the total set of 25 *before* surveys showed no significant difference on any of the five questions.

It is notable that the responses to the fifth question, related to the identification of effective ways to include sustainability in courses, did not show a significant change; considering this was a major objective of the workshop, this was a disappointment. Continuing work, however, will assess if faculty feel more confident in their ability to include sustainability after their first attempt to introduce a sustainability module to one of their courses.

Acknowledgements:

The authors wish to acknowledge the Purdue Engineer of 2020 Seed Grant Program, which provided support and expenses for the workshop, including small stipends for all faculty participants. Additionally, we thank Dr. Scott Matthews of Carnegie Mellon University and the Center for Sustainable Engineering for his assistance with development and facilitation of the workshop.

Bibliography:

1. World Commission on Environment and Development, 1987, ("The Brundtland Commission Report"), *Our Common Future*, Oxford University Press, Oxford.
2. Elkington, John, 1998, *Cannibals with Forks: the Triple Bottom Line of 21st Century Business*, New Society Publishers, Gabriola Island, BC, Canada.
3. ASCE, 2010. *Code of Ethics*, accessed Jan 10, 2010, at https://www.asce.org/inside/codeofethics.cfm
4. AIChE, 2010, *Code of Ethics,* accessed Jan 10, 2010, at http://www.aiche.org/About/Code.aspx
5. ASME, 2010, *Code of Ethics*, accessed Jan 10, 2010, at http://www.asme.org/Education/PreCollege/TeacherResources/Code_Ethics_Engineers.cfm
6. NSPE, 2010, *Code of Ethics*, accessed Jan 10, 2010, at http://www.nspe.org/Ethics/CodeofEthics.index.html
7. ABET, 2008, Engineering Accreditation Criteria 2009-2010, released Nov 1 2008; accessed Jan 10, 2010 at http://abet.org/Linked_Documents-UPDATE/Criteria_and_PP/E001_09-10 EAC_Criteria_12-01-08.pdf
8. Cardella, M.E., S.R. Hoffmann, M.W. Ohland, and A.L. Pawley, (in press, expected 2010), "Sustaining Sustainable Design through 'Normalized Sustainability' in a First-year Engineering Course," *International Journal of Engineering Education*, expected publication in volume 26, issue 2.
9. Chase, G.W., and P. Rowland, 2004, "The Ponderosa Project: infusing sustainability in the curriculum," in *Sustainability on campus: stories and strategies for change*, P.F. Bartlett and G.W. Chase, eds., MIT Press, Cambridge
10. Center for Sustainable Engineering, 2010, Website, accessed Jan 10, 2010, at http://www.csengin.org