

A TRANSDISCIPLINARY APPROACH TO SUSTAINABILITY EDUCATION

By

Liv Haselbach, PhD, PE, LEED™ AP, and Norbert Delatte, PhD, PE

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Introduction

As the human population of the world grows at an explosive pace, how can we strive for higher and higher standards of living without depleting the limited resources of Earth and its inhabitants? Is it possible to balance these increasing human needs with a consideration of both the built and the natural environments? An immediate follow-up question to our sustainability challenge is: “How can our educational programming and curricula—especially those in the many professional fields—be altered to include the issues and principles of sustainability?” To answer that question, it is worthwhile to review the state of sustainability education in one field for which the subject is now at the forefront of its learning objectives. Part One of this white paper provides that review for educational programs in civil and environmental engineering. Part Two points to possible broader, “transdisciplinary” (Oerther 2011) applications of the experience from various universities that prepare professionals in this field.

PART ONE

The Challenge in Civil and Environmental Engineering

The civil and environmental engineering field has focused on providing society with a built environment that meets human needs while protecting the natural world. Many of the more comprehensive ideas of sustainability are now being incorporated into the profession's practice as well as into higher education programs.

This change for the profession is being led by many groups. The report from a workshop sponsored by the National Research Council (NRC) of the National Academies recommends that our infrastructure become more sustainable by shifting the focus to include essential services and their interdependencies, cutting across jurisdictional and political boundaries to optimize investments and identify various objective solutions (NRC 2009).

Another leader of change is the Engineering Accreditation Commission of ABET, Inc. (ABET EAC 2010). ABET EAC sets the minimum accreditation standards for engineering programs in the United States, as well as some other countries. Sustainability is specifically mentioned in one of the 11 *Student Outcomes* under Criterion 3, where "student outcomes describe what students are expected to know and be able to do by the time of graduation" (ABET EAC 2010). Specifically, Criterion 3(c) requires that engineering students demonstrate "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" (ABET EAC 2010). Of course, Criterion 3(c) does not specifically require that engineering designs consider sustainability as a constraint, because it is only one of eight items mentioned in the list, but the list does contain various bottom-line aspects of sustainability: economics, the environment, and society.

It is left to engineering programs to determine how to consider sustainability as a constraint on design projects. In addition to the *Student Outcomes* criterion, ABET Criterion 5 on *curriculum* requires that "students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating appropriate engineering standards and multiple realistic constraints." Certainly, sustainability can be one of those constraints, although Criterion 5 does not mention it directly. Thus, ABET EAC encourages the consideration of sustainability in design, although the language does not reach the level of a direct mandate. The ABET EAC requirements are minimum standards, and programs are free to go beyond the minimums, although these engineering programs must achieve at least the minimums to maintain accreditation.

The American Society of Civil Engineers (ASCE) has gone beyond the ABET EAC minimums to define a Body of Knowledge (BOK) (ASCE 2008) for future civil engineers with a set of 24 outcomes, many of which are similar to the 11 ABET EAC outcomes. However, unlike the ABET EAC outcomes (which students should achieve before graduation), the ASCE BOK outcomes are intended to be fulfilled through a combination of a bachelor's degree, a master's degree (or equivalent continuing education), and professional experience before attaining Professional Engineer (PE) licensure. The ASCE BOK also defines six levels of achievement based on Bloom's Taxonomy of Educational Objectives, from the lowest, (Level 1) knowledge

or remembering through the levels of comprehension, application, analysis, and synthesis, to the highest (Level 6) evaluation (ASCE 2008). ASCE BOK Outcome 10, *Sustainability*, should be achieved through Level 3, application, at the bachelor's level, rising to Level 4, analysis, through prelicensure experience. These are further defined as attaining Level 3 by *applying* “the principles of sustainability to the design of traditional and emergent engineering systems. Implied is mastery of the scientific understanding of natural resources and the environment and the ethical obligation to relate these sustainably to the public interest. This mastery must rest on a wide educational base, supporting two-way communication with the service population about the desirability of sustainability and its scientific and technical possibilities.” Between graduation from a bachelor's program and professional engineer licensure, the engineer should learn to “*analyze* systems of engineered works, whether traditional or emergent, for sustainable performance. Analysis assumes a scientific, systems-level integration and evaluation of social, economic, and physical factors—the three aspects of sustainability” (ASCE 2008). The ASCE BOK also devotes a six-page appendix to sustainability.

The ABET EAC criteria are minimum standards that all engineering programs must achieve *now*, and the ABET BOK outcomes represent where the civil engineering profession aspires to be. Nevertheless, it is expected that ABET BOK will become increasingly embedded in civil engineering education at the baccalaureate and master's levels; therefore, this document's detailed attention to sustainability is encouraging.

Evolving Adaptations in Academic Programs

Many universities are leading the way by incorporating sustainability into their university vision, the surrounding community, and their curricula. One multiuniversity program that reaches out to educators across the nation in many fields, not only civil and environmental engineering, is the Center for Sustainable Education. This program is a joint venture among Arizona State University, Carnegie Mellon University, Georgia Institute of Technology, Syracuse University, and the University of Texas at Austin. Funded by both the National Science Foundation and the U.S. Environmental Protection Agency, the program is “dedicated to helping engineering professors update their courses and develop new ones to account for rapidly changing world conditions that are transforming the practice of engineering” (CSE 2011).

In addition, engineering departments throughout the nation have been exploring opportunities to incorporate sustainability into their programs in novel and multifaceted ways. Recent compilations of sustainability education research, case studies, and forums in the American Society of Civil Engineers *Journal of Professional Issues in Engineering Education and Practice* provide a plethora of adoption methods and goals, each addressing sustainability goals and the visions of the providers and educators. Summary overviews of the many forms in which sustainability is being incorporated into these curricula provide insight into the magnitude and complexity of the tasks ahead of us. At the same time, it is encouraging to see the successes and accomplishments that have been achieved in such a short time. When viewed together, the methodologies and techniques used at these universities seem extremely diverse, with no clearer view of how to continue in the future. These educational innovations cover a matrix of issues and considerations, with differing themes or topics, varying audiences, multiple delivery types and teaching methodologies, and even different delivery locations. Finally, the objectives and outcomes are being assessed in many ways, depending on the aspect of

interest and the needs of the department and the innovation. Table 1 provides an overview of some of the skill developments or themes used for teaching sustainability, the audiences and disciplines involved, and the delivery types reviewed in these programs and studies.

**TABLE 1: FIRST-STEP SUSTAINABILITY EDUCATION OPTIONS:
THEME, AUDIENCE, AND COURSE TYPES**

SKILL OR COURSE THEMES	AUDIENCE		DELIVERY TYPES
	<i>LIFE STAGE</i>	<i>FIELD (Singly or Multidisciplinary)</i>	
Life-cycle assessments [LCA] ¹⁰	High school ¹⁰	Civil and environmental engineers	Dedicated course: lecture/seminar ^{1, 2, 8}
Building information modeling [BIM] ¹¹	Undergraduate ^{2, 4, 5, 8, 10}	Construction management ¹³	Dedicated course: design ¹³
Transportation ¹⁰	Graduate ¹³	Other engineers ^{3, 11}	Incorporation into traditional courses ²
Carbon accounting ¹¹	Continuing education ^{8, 13}	Architects ¹³	Special modules ^{5, 6}
Energy [sector, fuels, or buildings] ^{3, 7, 10}	Faculty/educators ^{4, 13}	Scientists ^{8, 13}	Special projects
Environmental impacts ^{1, 7, 10, 11}			Curricula overlay
Buildings/infrastructure ^{9, 11, 13}			Comprehensive curricula ³
Manufacturing ²			Required or elective? ^{5, 1}
Society ¹²			
Water ¹			

The many items listed in Table 1 are not all-encompassing. There are opportunities for expansion in each category. Additional themes might include other resources, wastes, ecology, and planning. The audiences might be expanded to earlier, K–12 years or various stakeholders and decision makers. The delivery type might include courses taken outside one’s major or informal education venues.

¹ Apul and Philpot 2011
² Auredt and Butler 2011
³ Batterman et al. 2011
⁴ Bhandari et al. 2011
⁵ Bielefeldt 2011

⁶ Cattano et al. 2011.
⁷ Cohan 2011
⁸ Dvorak et al. 2011
⁹ Kevern 2011
¹⁰ Powers et al. 2011

¹¹ Stadel et al. 2011
¹² Valdes-Vasquez and Klotz 2011
¹³ Wolcott et al. 2011

In developing a course or program in sustainability education, after establishing the themes, the audience, and the course delivery method, various decisions must be made regarding teaching methodologies, course locations, and the determination of outcomes and assessments. Again, these innovations in civil and environmental engineering education provide a vast menu of options for these additional considerations, as noted in Table 2.

**TABLE 2: DETAILED SUSTAINABILITY EDUCATION OPTIONS:
TEACHING METHODS, SITE, AND ASSESSMENT**

TEACHING	LOCATION	ASSESSMENTS
<i>Methodologies</i>	<i>Courses</i>	<i>Tools</i>
Life-cycle/systems approach¹⁰	Outdoor spaces¹	Bloom’s taxonomy— traditional¹
Comparative metrics [e.g., pollutant emissions, \$]⁷	Classrooms⁴	Fink’s extension to human dimension¹
With mentors/practitioners¹²	Studios¹²	Diffusion of the educational innovation¹²
Concept mapping^{3,11}		
<i>Focal Areas</i>	<i>Intern Activities</i>	<i>Assessing</i>
Basic engineering principles⁷	Academic	Knowledge of participants⁵
Sustainability principles (e.g. social, biomimicry)^{6,11}	Workplace	Future impacts on participants^{2,8}
Growing technologies⁹	Community	Impact on those associated with participants¹²

Tables 1 and 2 show how the initial incorporation of sustainability education into a single discipline—civil and environmental engineering—is not a one-size-fits-all process. Various items have been considered for course and program development, yet all of the aforementioned educational innovations are successful, according to their implementers or users.

As we then plan to expand sustainability education in this field and into others, what can we learn from these early innovators? Are there any consistent themes? The details of the multiple pairing of these topics or skills from a group of sustainability education trials appear in Table 3.

¹ Apul and Philpott 2011

² Aurandt and Butler 2011

³ Batterman et al. 2011

⁴ Bhandari et al. 2011

⁵ Bielefeldt 2011

⁶ Cattano et al. 2011

⁷ Cohan 2011

⁸ Dvorak et al. 2011

⁹ Kevern 2011

¹⁰ Powers et al. 2011

¹¹ Valdes-Vasquez and Klotz 2011

¹² Wolcott et al. 2011

In reviewing the programs that are developing sustainability education, two processes appear to be intertwined: *integration* and *communication*. Each course or module integrates two or more topics or skills around one or more themes. From this, one or more disciplines then learn communication skills, including broadened conceptual understandings, outside their more discipline-oriented core.

With this analysis done and these two key processes identified, it is reasonable to raise the question of applicability beyond the academic discipline and professional field of civil and environmental engineering.

PART TWO

The urgent question that focused the research for Part One of this paper was, “How can our educational programming and curricula—especially those in the many professional fields—be altered to include the issues and principles of sustainability?” Having identified *integration* and *communication* as two overarching and key answers to that question, other immediate questions lead to some possible next steps that enable sustainability principles to be embedded in society through the formal educational system. Below are three such questions and answers based on our research efforts for this paper.

1. Are *integration* and *communication* also common themes in other sustainability education innovations?
2. Can we use these two common themes as templates for incorporating sustainability education into other disciplines and at other levels of education?
3. Can we also use the two themes of *integration* and *communication* as templates to incorporate sustainability more effectively into practice and everyday life?

Question 1: Yes, integration and communication are also common themes in other sustainability education innovations. At Cleveland State University (CSU), the bachelor of civil engineering curriculum culminates in a two-semester team capstone design project. *Sustainability* is one of the design constraints, and the student groups address it specifically in their final design reports and presentations. So far, implementation has been uneven. In spring 2011, for instance, the students responded by designing a green roof for every building design project, regardless of whether it was the most appropriate solution. This highlighted the need to build sustainability concepts into coursework earlier in the curriculum. The CSU curriculum was recently changed to require a new course, Engineering History and Heritage, which examines the development of engineering and technology through case studies that include a consideration of sustainability. As an example, the sustainability of our current petroleum economy is *integrated* into a case study of the development of petroleum refining. This course is offered sophomore year, so in two years it will be interesting to note whether the team capstone design projects address sustainability in a more robust manner.

At Syracuse University, Cliff Davidson teaches a sophomore survey course on sustainable engineering, which *integrates* energy, materials, water and air quality, and population modeling. Transdisciplinary *communication* is also manifested at Syracuse University with a Business School graduate course on entrepreneurship in sustainability.

Question 2: The themes *integration* and *communication* serve as templates for incorporating sustainability education into other disciplines and at various levels of education. The Center of Excellence for Careers in

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Education at Green River Community College (GRCC) *integrates* workforce training to expand and strengthen programs to meet the educational and training needs of ever-changing industries (GRCC 2011). Graduate and undergraduate students in various disciplines, faculty, and practitioners involved with the year-long Integrated Design Experience (IDeX) course at Washington State University have used this opportunity to come together and develop novel visions and designs for both a community-sponsored agriculture project and the development of a growing city into a center for green innovation. Concurrent research on the IDeX innovation is developing a model for diffusion of the sustainability benefits not just within the course, but also to other faculty and practitioners (Wolcott et al. 2011).

Question 3: Yes, we can use the themes *integration* and *communication* as templates for incorporating sustainability into practice and everyday life. Some examples include the students and researchers from both the United States and Peru who together came up with novel and sustainable ways to improve indoor environmental quality in a remote, high-altitude region of Peru, combining thermodynamic principles of mechanical engineering with indoor air quality improvement, while considering the social and regional resources and customs of the region (Montoya and Harman 2011). Project-based curriculum requirements at Worcester Polytechnic Institute require students to interact not just in engineering, but also with the arts and humanities and social sciences, culminating in many capstone interdisciplinary projects that have a global impact (Plummer 2011). On a larger scale, the National Research Council finalizes its recommendations for Sustainable Critical Infrastructure Systems in stating that “an important first step in creating a new paradigm is to bring together those who have an essential stake in meeting 21st century imperatives . . . Such a gathering could serve to initiate a longer-term collaborative effort . . . The results could be critical infrastructure systems that are physically, economically, socially, and environmentally sustainable for the next 50 years” (NRC 2009).

An example of the use of *integration* and *communication* to partially address all three of the questions, even in a single-course setting, is the graduate mini-internships that are part of the two-semester-long sustainability engineering classes at Washington State University and that have been recently introduced into a sustainability engineering course at the University of South Carolina. These service-based projects count as part of a graduate student’s grade in these three classes, and they show the flexibility of these approaches and innovations among a wide variety of themes, topics, and audiences. Over the last three years, the projects have included “loaning out” graduate engineering students as:

- Consultants to other design classes;
- Interns for campus development or other university departments;
- Researchers for small green projects on campus, such as bike lanes or recycling programs;
- Interns for community projects, such as stormwater programs or stream restorations;
- Special projects for employers, such as green rating evaluations and recycling programs;
- Supplementary research assistants for other researchers on exploratory issues; and
- Assistants for developing sustainability modules for courses at or beyond the university.

The value of *integration* and *communication* in bridging the graduate students' education with others in the community, the workplace, and beyond is evident in the following quotes from the participants in various applications of this mini-internship educational innovation.

- A Bridge Between Two Courses
Example of engineers helping in various architect studios:
 - “I want to thank you again for loaning me the grad students. The architecture students found them extremely helpful. It was a great thing.”
 - “Thinking like an Architect . . . The project has given me a lot of insight about architecture design . . . I would do it again if I had the choice.”
 - “It forced me to step out of my own comfort zone and enabled me to gain new perspectives on the way other professionals function.”
- A Bridge to Our Campus/Community
 - Tree tagging project: “. . . using innovative techniques . . . backed by engineering . . . will help architects and landscape planners. . . The experience was definitely worthwhile and it felt good to help the school.”
 - Mapping existing bike paths . . . “realized some of the constraints . . . Coordination was the key . . . This process was educational for me.” (This and a previous bike survey led to two proposals for additional bike lanes on campus. Seven students were involved over 18 months.)
- A Bridge to Employment
 - Proposing a recycling program for one's employer: “. . . excellent teaching tool . . . It allowed me to first see a problem . . . and work for a solution . . . It enabled me to complete my first independent research.”
 - Mapping buildings for green rating consideration for employer: “This assignment was perfect . . . It rejuvenated my interest . . . It proved useful . . . was a huge learning opportunity.”
- A Bridge to Further Education
 - Two participants interning for educational application assessment of integrated courses are now PhD students in engineering education (Haselbach et al. 2011).

These service projects cover a wide range of options and do not necessarily have *sustainability* in their titles. The only consistencies are engineers *integrating* and *communicating* with others they might interact within their professional lives. The graduate students learn what other professions do, perhaps how others perform these skills and how complex that might be. Finally, the graduate students are communicating with each other. Is this not what sustainability engineering is all about—performing in one's discipline while being aware of other important issues in the world? Sustainability education and outreach may not impact everyone, in every way, but if each discipline sought to reach out to others in more ways, the web of sustainability could become more and more connected and eventually stronger.

The Future

Thus, the concepts of *integration* and *communication* can be broadly applied in many ways to further the sustainability goals in our educational systems and in practice. The disciplines and topics with which our discipline might need to interact should be based not only on current educational and technological needs but also on anticipated educational needs, technological advances, and futuristic opportunities not yet imagined. If we do not *integrate* and *communicate* with others, how will we know about the sustainability solutions for the world that have yet to be brought about?

What is your next step? How might your university or school begin to incorporate or expand sustainability into its program without suffering by competing with core competencies or limited resources? This might be accomplished by repeating a three-step cyclic process that eventually incorporates sustainability into large courses and as a full curriculum overlay within the discipline or university wide.

1. **Get Ready:** Overview the topics and disciplines that your students and faculty might interact with, both today and in the future.
2. **Get Set:** Try various methods, formats, and audiences to initiate *integration* and *communication* with these themes and disciplines using available resources and willing personnel.
3. **Go:** Evaluate and efficiently identify additional needs and resources for expanding the sustainability innovations into a more comprehensive program, and continue to respond to future needs and technological advances.
4. **REPEAT**

In summary, the two trends *integration* and *communication* are centered about a common theme or goal to take the first steps toward sustainability education. This can be initiated with the resources available and those excited to be part of the mission. These first steps need not involve extensive resources, just small but meaningful efforts at *integration* and *cross-communication*. It works. Then it is time to take a step back, to see where the strengths are with the innovations already started and to look for any holes that need to be filled to embrace sustainability in a more comprehensive way. Those holes can then be filled, but with strengths already realized in a more efficient and economical way.

Then, is that the end of the process? Of course not! Part of sustainability is adapting to the world and its needs, so educators must understand that the process is iterative—little steps turn into wider-spread arms, always reaching to embrace more of the world, its people, and their needs.

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