Use of Outdoor Living Spaces and Fink's Taxonomy of Significant Learning in Sustainability Engineering Education

Defne S. Apul, Ph.D., EIT[1]; and Stacy M. Philpott[2]

1

Abstract: Previous sustainability engineering education studies have suggested the importance of problem-based learning, project-based learning, team-based learning, and interdisciplinary learning. Place-based learning, interacting with outdoors, and building sustainable communities are also important aspects of sustainability education, yet relatively little has been published on how to use these pedagogical approaches in engineering education. The goal of this paper was to illustrate the implementation of all these pedagogical approaches in a graduate-level sustainability engineering education class. Fink's taxonomy of significant learning and the University of Toledo's Outdoor Classroom Garden provided the framework for this implementation. Throughout the semester, sustainability engineering students worked towards an engineering solution for how to water University of Toledo's outdoor classroom garden. They also estimated the life-cycle cost and environmental impacts of their proposed solutions. The garden project and the design of the course provided many different learning opportunities that might be absent in a traditional civil engineering class. **DOI: 10.1061/(ASCE)EI.1943-5541.0000051.**

CE Database subject headings: Sustainable development; Engineering education.

Author keywords: Garden; Sustainability engineering; Civil engineering; Fink's taxonomy of significant learning; Problem-based learning.

Introduction

Civil and environmental engineers play a critical role in sustainable development because they have expertise in designing and improving primary infrastructures that serve human needs. Designing transportation infrastructures, buildings, and water and sanitation services in accordance with sustainability concepts will be critical in sustaining human well being on earth. Civil and environmental engineers also solve environmental problems such as creating waste treatment facilities, recycling resources, and protecting and restoring polluted sites and natural ecosystems. Many civil and environmental engineering programs in the U.S. have begun changing their curriculums to train a different kind of engineer who can analyze sustainability of built environments and design and engineer sustainable systems. We are currently in the last third of the United Nations (UN) Decade of Education for Sustainable Development (2005-2014), and many civil and environmental engineering departments across the U.S. have either incorporated sustainability concepts into existing courses or have significantly redesigned the curriculums for better alignment with sustainability (Huntzinger et al. 2007; Murphy et al. 2009).

A rapidly growing body of sustainability engineering education literature shows that sustainability education is transforming not only the content but also the format of engineering education (Cooper 2007; Davidson et al. 2007; Tam 2007; Kelly 2008; Chau 2007; Huntzinger et al. 2007; Riley et al. 2007; Segalas et al. 2010; Wang 2009; Ahn 2009). For example, active learning methods such as problem-, project-, and team-based learning have already infiltrated engineering education (Aparicio and Ruiz-Teran 2007; Quinn 2008; Ponsa et al. 2009). But the use of active learning techniques are even more prevalent (e.g., Chau 2007; Cooper 2007; Riley et al. 2007; Quist et al. 2006) and critical (Huntzinger et al. 2007) for sustainability engineering education. Huntzinger et al. 2
(2007) note that to successfully apply sustainability principles and ideas in the engineering profession, students need to develop intellectually, and such development can only be achieved using active learning techniques that expose students to complex, open-ended problems often with conflicting goals. In addition, sustainability engineering is interdisciplinary (Mihelcic et al. 2003). Therefore, a teaching environment that provides opportunities for diverse disciplines to converge on a problem is critical for sustainability engineering education. With this idea in mind, some schools (e.g., Arizona State University, Rochester Institute of Technology) have developed interdisciplinary sustainability programs (ASU 2010; RIT 2010).

Previous studies, therefore, suggest that sustainability education should incorporate problem-based, project-based, and team-based learning and interdisciplinary learning. While not widely discussed in the sustainability engineering literature, place-based learning, interacting with outdoors, and building sustainable communities are also important aspects of sustainability education. The goal of this paper is to illustrate the implementation of all these pedagogical approaches in a graduate-level sustainability engineering education class. Fink's taxonomy of significant learning and University of

[1]Assistant Professor, Dept. of Civil Engineering, Univ. of Toledo, 2801 W. Bancroft St., Mail Stop 307, Toledo, OH 43606. E-mail: defne .apul@utoledo.edu

[2]Assistant Professor, Dept. of Environmental Sciences, Univ. of Toledo, 2801 W Bancroft Ave, Mail Stop 604, Toledo, OH 43606, E-mail: stacy .philpott@utoledo.edu

Note. This manuscript was submitted on March 19, 2010; approved on August 27, 2010; published online on July 29, 2010. Discussion period open until September 1, 2011; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Professional Issues in Engineering Education & Practice***, Vol. 137, No. 2, April 1, 2011. ©ASCE, ISSN 1052-3928/2011/2-0–0/$25.00.

Toledo's outdoor classroom garden provided the framework for this implementation. Throughout the semester, sustainability engineering students worked toward engineering a solution for how to water University of Toledo's outdoor classroom garden. The garden project provided various learning opportunities for both students and faculty involved. Since the garden played a special role in sustainability instruction, this paper also includes a discussion of how the garden fits into the overall scheme of sustainability education.

Outdoor Classroom Garden Addressing an Educational Need

The classroom experience for a typical university student can be compared to growing a seedling in a hot house. Sheltered and insulated, college courses often operate under a single disciplinary focus thereby excluding students from the natural interdependency of content, culture, and learning. Separating our environment (our world) from our culture (the way we view the world) denies their interdependency in framing how we make sense of what we learn (Cronon 1995; Cole 2007). Yet, one could envision an education system that follows an ecological model with various disciplines combining to produce an interdependent, complex system. This interaction of engineering, nature, economics, society, history, politics, and culture not only leads to better understanding of specific content areas but also promotes the collaboration needed to solve some of today's most troubling problems (Everett 2008).

The implications of these ideas on engineering education are vast. Engineering is an applied field, yet in the 20th century, engineering education moved from being practice-oriented to science based (Aparicio and Ruiz-Teran 2007). Within this path, engineering education focused more on theoretical concepts and the implications of the practical applications of the engineering design solutions and thus the interdisciplinary implications of the engineering process was to some extent lost within the curriculum. Archizewski and Harrison (2010) noted that engineering education was to a certain extent reduced to highly repetitive routine work and this lack of creativity and connection to society and other fields may have motivated students to select other professions.

Outdoor living spaces such as gardens and green roofs can provide unique opportunities to address issues faced by higher education, including engineering education. For example, engineering students learn inside buildings typically using common engineering textbooks. Inside the building, often, most lines are parallel, most things are uniform and there is little indication of the specific cultural and natural history and complexity of the place. Thus, students can have difficulty visualizing that real world engineering problems are placed-based, complex, heterogeneous, nonlinear, and require interdisciplinary solutions. Indoor learning has other negative learning implications due to confinement to a limited space and exposure to artificial lighting. It is now well documented that using natural light inside buildings can largely improve the productivity and health of occupants as it simulates a more natural world than an artificially lighted space (Edwards and Torcellini 2003).

The benefits of learning outside, while intuitively credible, have recently been validated through scientific research. A University of Michigan study found that spending time in natural settings (versus an urban environment) restored and improved the cognitive functioning of the brain (Berman et al. 2008). Furthermore, simply spending time in nature and talking about it can increase engagement in environmental fields and dedication to fighting for the natural world (Chawla 2002).

Outdoor living spaces also offer other educational benefits. Combining student learning with the environment, particularly in settings linking learning with community responsibility, improves community college student self-esteem, quality and quantity of student academic work, and student involvement in campus and/or community activities (Hoffman et al. 2007). Through development and maintenance of a community garden, students take ownership for it, find it a place for quiet respite, and develop stronger bonds with their college or university that may eventually lead to improved retention rates (Ozer 2007). To have these effects, however, the garden must be sustained through effective integration into the curriculum and through continued support from all stakeholders (Azuma et al. 2001). To achieve effective integration of a classroom garden into a curriculum, it is essential that faculty members accept and practice the interdisciplinary nature of higher education (Ozer 2007).

Over the past 20 years, many universities have been moving instruction outdoors. Frequently, these classroom gardens are used to teach science and nutrition (Ozer 2007). Gardens and smaller sized student farms can be used to teach about sustainable agriculture and food systems and related topics such as anthropology, entomology, environmental sciences, soil science, and agricultural, food, and natural resource economics. For example, the Michigan State University (MSU) interdisciplinary specialization in Sustainable Agriculture and Food Systems has strong links to various traditional departments and to the MSU Student Organic Farm (SAFSS 2010). However, an outdoor classroom garden has not been previously incorporated or related to civil engineering education as a means to train students on sustainability engineering.

Inception of the Outdoor Classroom Garden

For about one year, a few faculty members conceptualized and planned for the Outdoor Classroom Garden and obtained support from students and administrators. On Earth Day, April 22 2009, the University of Toledo broke ground for the Outdoor Classroom Garden. Since its inception, the garden activities have been coordinated via a central steering committee comprised of faculty volunteers (two from the Environmental Sciences Department and one from the Women and Gender Studies Department) and one to two Department of Environmental Sciences graduate teaching assistants.

The garden is located on the main campus of the University of Toledo, adjacent to the Department of Environmental Sciences. It is approximately ~600 m^2, and includes 19 individual beds of various sizes surrounded by wood-chip covered pathways. The garden also includes a lawn area in the center (~75 m^2) to be used as a physical classroom or meeting space.

The garden was envisioned as a means to coalesce the campus community on sustainability education. To improve sustainability, it is essential to provide university faculty and staff with time and guidance to learn about sustainability, to reflect upon best practices, and to transform the way they teach to embrace sustainability concepts (Moore 2005). The garden was envisioned to promote these concepts initially by focusing on sustainable agriculture, plant and soil science, nutrition, and ecofeminism in an urban setting. However, as the concept and actual implementation of the garden evolved and with participation by one of the writers of this manuscript, the relevance of the garden to other fields such as engineering and sustainability engineering education also became increasingly relevant.

Course Design and Philosophy

Since the garden at the University of Toledo is fairly new, it has thus far transformed only one course in the college of engineering:

sustainability engineering and science, an annually offered civil engineering department graduate level course. This course was developed and taught in fall of 2008 for college of engineering students and with anticipation that it could also attract environmental sciences department graduate students. In its first offering, there were eleven civil engineering students and one environmental science student. In 2009, the Outdoor Classroom Garden was incorporated into the course and the course was transformed from one that incorporated problem-based learning to one that extensively relied on problem-based learning to meet course objectives. Enrollment was low (four graduate students) in 2009, a factor which may have simplified the transformation efforts. Expected annual enrollment for this course is approximately 10 graduate students.

The authors' experience with this and other classes suggests that if more than 15 students are enrolled, the amount of time required to manage the project and problem-based approach can increase considerably, and in those cases the emphasis on one single large problem may need to be reconsidered. Based on the writers' experience, two critical conditions for successful problem- and project-based classes are positive group dynamics and effective and meaningful contribution of each student to the overall project goal. When the student to instructor ratio is high, the instructor may not be able to effectively provide the individual attention necessary to meet these conditions.

Three related pedagogical approaches formed the fundamental design of the sustainability engineering course: Fink's taxonomy of significant learning (Fink 2003; Fallahi et al. 2009), team-based learning (Fink 2004), and problem-based learning (Savery 2006; Barroso and Morgan, 2009). Using these concepts, a project is developed every year for students to work on. Problem-based learning and project-based learning are similar approaches in that in both methods, "activities are organized around achieving a shared goal (project)" (Savery 2006). In the sustainability engineering course, problem-based learning was preferred over project-based learning because problem-based learning assumes greater responsibility for students by requiring them to define the problem and set the parameters, goals, and outcomes of the problem. In contrast, in project-based learning, the instructor determines the final outcome, e.g., design a rainwater harvesting system for the garden, and students' learning experience primarily relies on following correct procedures, e.g., hydraulic calculations (Savery 2006). In team-based learning, high performance learning teams are developed and they are provided with opportunities to engage in "significant learning" tasks (Fink 2004).

Fink's taxonomy of significant learning encompasses the ideas included in problem-based, project-based, and team-based learning. Bloom's taxonomy (Bloom 1956) has been the primary reference for educational outcomes in ABET (Besterfield-Sacre et al. 2000) and body of knowledge documents for environmental and civil engineers (AAEE 2009; ASCE 2008). Fink's taxonomy expands on Bloom's taxonomy and is more comprehensive as it includes categories such as learning how to learn, the human dimension of learning, and the caring dimension of learning (Table 1).

Previously, use of these approaches in the class and student assessment based on these methods was limited to no more than half of class efforts. In fall 2009, the garden project was envisioned with the garden planning committee as a full blown project that would transform the learning environment in this class. The instructors and students mutually agreed for the project to constitute 85% of the students' course grade. Since such a heavy project-based approach is new to students, it was important to introduce the "unusual" class format to students early in the semester.

Learning objectives were developed for each of the six categories included in Fink's taxonomy (Appendix I). On the first day of the semester, Fink's taxonomy and the associated course-based learning objectives were discussed with the students. In addition, the new paradigm used in this class was compared to the old, traditional paradigm (Table 1). The enhanced benefits of incorporating Fink's ideas into the course and going beyond Bloom's model were also discussed with students. Thus, students knew up front the unusual structure and expectations of the class.

In retrospect, some deficiencies are noted in the learning objectives developed for the class. For example, project-based and team-based learning are integral parts of the class but were not explicitly included in the learning objectives. In addition,

Table 1. Comparison of old and new teaching paradigm [adapted from Fink (2003)]

	Old paradigm		New paradigm
Knowledge	Transferred from faculty to students		Jointly constructed by students and faculty
Learning refers to	Bloom's taxonomy: 1. Knowledge 2. Comprehension 3. Application 4. Analysis 5. Synthesis 6. Evaluation	Similar	Fink's taxonomy: 1. Foundation 2. Application 3.Integration,
		Additional	4. Learning how to learn (becoming a better student, inquiring about a subject, self-directed learners) 5. Human dimension (learning about oneself and others) 6. Caring (learning new feelings, interests, values)
Student	Passively receives knowledge from faculty		Actively constructs, discovers, transforms knowledge
Mode of learning	Memorizing		Relating
Faculty purpose	Classify and sort students		Develop students' competencies and talents
Context	Competitive, individualistic		Cooperative learning in classroom
Power	Faculty holds and exercises power, authority, control		Students are empowered; power is shared among students and between students and faculty
Format	Lecture- based		Project based, team based, and using multiple dimensions of learning as given in Fink's taxonomy of learning
Assignments	Close-ended problems that have a single answer and are often repetitions of previously shown problems.		Both close-ended and open-ended problems.

students did not develop "reflection" skills. Riley et al. (2007) introduced a "Sustainability in Higher Education Assessment Rubric" (SHEAR). Based on this rubric, a sustainability course should include knowledge and awareness, skill development, responsibility, lifelong learning, application in diverse setting, diverse interactions, partnerships, and reflection. The sustainability engineering and science class was deficient in reflection opportunities. Other SHEAR related aspects were included in the class design but not explicitly discussed with the students.

Student Work in the Sustainability Science and Engineering Course

Possible projects for the sustainability engineering class were discussed with the garden steering committee prior to beginning of the semester. Two possible projects emerged from these discussions. There was interest in building a composting facility and a composting toilet close to the garden to enhance the sustainability practices associated with that space. Yet, in addition, there had been issues in the past with watering the plants in the garden. The garden was watered using a fire hydrant in the summer of 2009. The fire hydrant broke and the garden team then arranged for a water tank to be hauled by the University of Toledo Grounds Department to the site every other week. Staff from the Grounds Department filled the tank trailer with municipally supplied potable quality water and pulled it to the garden, but not on a routine basis. This arrangement was an increased effort and cost for the Grounds Department and the unstructured and off-schedule hauling of the filled tank trailer created a planning problem for the garden steering committee. In addition, the graduate teaching assistants and other garden volunteers had to be on-site to pump the water from the tank to the garden using hoses that had to be moved from one site to the other so as to water the entire garden. While both the composting and the watering project topics would have worked well as a sustainability engineering project, the latter was selected as the project topic because of the urgent need of a solution for watering the garden.

The garden steering committee served as the "client" in this problem-based approach and met with the students at the garden to introduce and explain the watering problem. The students then met with the instructor to determine the problem statement and project scope. The students and the instructor collectively identified the goal and outcome of the project as developing solutions to the watering problem, evaluating the feasibility, cost, and life-cycle impacts of these solutions, and making a final recommendation to the client based on this evaluation.

Mandatory submission of three progress reports: one final report, one midsemester presentation, and one final presentation, facilitated timely progress of students. In addition, these deliverables served as formal means for the instructor and the client to provide timely feedback to students. These deliverables were also used to assess student learning and progress in class, ultimately culminating in 85% of course grade. The grading scheme for these deliverables included both content and effectiveness of the delivery (Appendix II). In this way, students learned about their current weaknesses in knowledge and skills and aimed to strengthen these weaknesses prior to submission of the next deliverable.

The garden steering committee and the instructor provided technical help to students and directed students to other experts where needed. For example, students worked with contractors to evaluate the irrigation and well drilling options (e.g., sprinklers versus drip irrigation and drilling into bedrock); worked with plant scientists to estimate the garden annual water demand; worked with a hydrologist to determine the possible groundwater yield at the site; worked with a surveyor to develop an AutoCAD drawing of the site and elevation of various points on-site; and worked with graduate students from the Civil Engineering Department to discuss cistern sizing calculations and the Department of Environmental Sciences to collect garden data including plant types used at the garden. Through these different aspects of the work, students were exposed to interdisciplinary learning. They also got a chance to get out of the classroom and explore the real world.

Students developed, evaluated, and compared six design solutions; (1) obtaining rainwater from roof runoff of a nearby building and storing this rainwater on-site using a cistern; (2) pumping water from the on-site aquifer, (3) fixing and continuing to use the fire hydrant, (4) obtaining water from a nearby river, (5) constructing an on-site water tank that can be filled with potable water hauled to the site by grounds department, and (6) a business as usual (BAU) case where a water tank trailer is hauled back and forth by the Grounds Department to water the garden on-site. Students estimated the life-cycle cost, feasibility, and (qualitative) sustainability of each option and narrowed the options to obtaining rainwater from roof runoff and the BAU case. The students then designed and sized the rainwater system which included a pump, pipes, a cistern, and a drip-irrigation system. In addition, the students developed a potential solution to the technical challenge of moving rainwater from the collection site to the garden over a nearby road. Once the system was designed, the students then conducted a more thorough sustainability analysis of these two options by using life-cycle assessment to estimate the energy demand and CO_2 emissions. They also calculated the energy and CO_2 emission payback periods of the proposed system. Life-cycle impacts were limited to estimations of energy use and associated global warming impacts because the water-energy connection is often not intuitive for students and quantifying this connection and associated CO_2 emissions can be an effective way to understand this connection. The use of energy and the carbon footprint as the sustainability metrics of the project also conformed to the current common sustainability practice of today's organizations.

The project results showed that the cost of the installation of the rainwater system would be approximately $15,000. Students estimated that the energy demand and CO_2 equivalent emissions of the rainwater system would initially be higher than the BAU case but the rainwater system would outperform in the long run because of the lower energy demand and emissions of the operation phase. Students estimated that the rainwater system would have emitted less CO_2 than the current system after five years. Similarly, it was estimated that the proposed system would have consumed less energy than the current system after the eighth year of instillation.

At the end of the semester, students shared their final report with the instructor and the client. In addition, they presented their results to a wider audience that included faculty and students from multiple departments. During the presentation, the garden steering committee raised an interesting suggestion that students had not considered: the possibility of building a toolshed on-site that could be used to collect rainwater. Students then did additional analysis to report back to the client on the minimum toolshed roof area needed to meet the watering demand of the garden.

Evaluation of Foundational Knowledge and Application Aspects of Fink's Taxonomy of Significant Learning

Competency in *foundational knowledge*, which relates to students' ability to remember and understand many different types of

Table 2. List of knowledge (some new and some adopted from other resources) constructed by students. This list was developed from students' final report and instructor's knowledge of students' project related activities during the semester

Knowledge constructed	How was knowledge constructed?[a]
List of classes that have used the garden	Obtained information from Garden steering committee
Reason for initiation of garden on UT campus	Compiled from Garden steering committee, published news articles about the garden, and garden website
Watering requirements of the garden	Meeting with a plant science faculty, application of methods described on internet based resources, comparison of results estimated using different methods
Site description: soil type and characteristics, plant species	Meeting with geology faculty, Lucas County Soil Survey Book
Site description: site topography	Meeting with surveying faculty, site visit, use of GPS equipment and AutoCAD software
Site description: existing pump and irrigation properties	Site visit, internet search on the specific pump used on-site, discussions with the Garden Steering Committee
Cost for watering	Compiled from multiple sources including the instructor, internet, and the University of Toledo grounds department
Cost for gas used in pump	Calculated from estimated water demand and assumed cost of gas per gallon
Identification of alternative design solutions	Determined based on collected information and discussions with instructor, geology faculty, peers, and garden steering committee
Feasibility of excavating a well on-site	Analysis completed after collecting data and ideas from geology faculty, local drilling company, internet
Feasibility of drawing water from a nearby creek	Analysis of creek conditions and proximity to site (using Google Earth)
Feasibility of using existing fire hydrant	Analysis completed based on discussions with garden steering committee and internet research on fire hydrants
Rainwater harvesting system analysis and design: system components, tank types and costs, hydraulic calculations, system sizing	Analysis involved internet research, meetings with instructor's research assistant, meeting with hydrology faculty, pipe headloss calculations, use of Texas Rainwater Guide spreadsheet
Summary and comparison of alternative design solutions	A table was developed to compare previously constructed information. Table was used to justify selection of developed information.
Evaluation and design of drip irrigation system	Involved internet research and meeting with a local irrigation company
life-cycle cost, energy and greenhouse gas emissions estimates of base scenario and rainwater harvesting solution	Cost was estimated from phone conversations with vendors and from internet research; energy and emissions were estimated from EIOLCA; previous LCA lectures, exercises and homework provided the knowledge base for EIOLCA analysis
Payback periods of proposed solution	Graphing was used to determine the year at which the proposed solution yield less cost, energy, and greenhouse gas emissions than the base scenario

[a]Note: Students had discussions with the instructor while constructing each piece of the knowledge. However, to avoid repetition, the instructor's role in constructing knowledge is not included in each row. Some knowledge was transferred from the instructor to students, other discussions involved instructor referring students to particular resources.

information and ideas, was evident in the final report and in the final presentation. Since students submitted multiple deliverables throughout the semester, the instructor was able to identify students' knowledge and skill gaps from these deliverables, which were consequently gradually filled in prior to submission of the final report and presentation. The students' learning culminated in a 35 page single-spaced report containing a large amount of newly constructed information (Appendix III and Table 2). It is interesting to note that the knowledge constructed by students as evidenced in the report had little overlap with the list of foundational knowledge included in the learning objectives section of the syllabus (Appendix I and Table 2). life-cycle assessment was the only concept included both in the syllabus and in the final report. This is an outcome of problem-based learning. The instructor did not know ahead of time the complete list of knowledge students would learn since students were made responsible for determining the scope, parameters, and outcome of the project. Had these parameters been previously determined and provided to students, the class activities would resemble that of project-based and not problem-based learning. Note that the concepts included in the syllabus but not in the report (e.g., biomimicry, LEED, water footprint) were still part of the class but not the project; these concepts were assessed in the remaining 15% of the students' grade.

In Fink's taxonomy of significant learning, *application* refers to application of skills, managing projects, and critical, creative, and practical thinking. Each student managed his/her own part of the project. In addition, one of the students assumed the responsibility of the project manager and therefore practiced additional project management skills. Peer grading and weekly in class discussions of each student's current tasks helped the instructor evaluate and provide timely feedback on students' project management skills. Since the garden project was an actual problem, critical (e.g., students compared and narrowed design solutions to a single recommended alternative), creative (e.g., students developed a potential solution for technical challenge of moving rainwater over a nearby road), and practical (e.g., design of overflow system for rainwater tank) thinking skills were necessary for successful completion of the project. The design of the course, including the grading scheme, also gave students opportunities to practice and improve their oral presentation and technical writing skills throughout the semester. Finally, technical skills such as LCA analysis, cost estimation, and rainwater system evaluation and design were apparent in the final report (Table 2 and Appendix III).

Other Opportunities that the Garden and Problem-Based Learning Offered

Incorporation of the garden project in the course offered some unique learning opportunities for the civil engineering students. For example, students spent several hours visiting and studying the site. Thus, the education was ultimately partially taken outside of the building and students got a chance to interact with nature.

Learning how to learn (become a better student, inquiring about a subject, self-directed learners) is one of the six items included in Fink's taxonomy of significant learning. Self-direction in learning was apparent from the beginning of the class. By themselves, students identified the knowledge base and technical skills they needed to solve the problem; they then had to inquire about the knowledge base and skills to develop their competencies in them.

The knowledge base and technical skills students developed are evidenced in the final report and final presentation (Table 2 and Appendix I). Students constructed and integrated many types of new information, some of which was unusual for a civil engineering class. For example, the students' final report on the garden description and in-class discussions on how to properly estimate the garden water demand suggested that students learned some new plant names (marigolds, *Calendula* spp., *Cosmos* spp., *Salvia* spp., and *Nasturtium* spp.) while interacting with faculty and students from the Department of Environmental Sciences. Such terminology would typically not be a part of a traditional civil engineering class. Technical skills the students developed include designing and sizing hydraulic systems and evaluating the life-cycle cost and environmental impacts of these engineered design solutions. In traditional classes, students rely primarily on their lecture notes, their books, and homework assignments in developing their knowledge base and skills. In this class, with the instructor acting as a facilitator, the students employed many other learning strategies such as searching for information on the interest and
3 meeting with multiple experts and companies.

The project format appears to have benefited the students' learning of life-cycle assessment. During the semester, students listened to two lectures on life-cycle assessment, completed a hands-on life-cycle assessment exercise (on economic interactions and corresponding waste outputs of industrial sectors), and a simple life-cycle assessment assignment. At the end of the semester, all of the students noted that they had not really understood or appreciated the life-cycle assessment method until they actually used it to solve the watering problem. The garden project seems to have changed students' perspective on life-cycle assessment from one of confusion and irrelevance to one of a valuable tool to be used in problem solving.

The student course evaluations were positive and suggested that students enjoyed the project and the class. The instructor and members of the garden steering committee also agreed that this project was a major success as well as a learning opportunity for students. Both the students and the instructor were surprised by the quality and depth of information of the final report and presentation. Initially, students had thought that this project was undoable within a semester, but the real life and place-based aspect of the problem, its sustainability challenge, and the social context the project provided seem to have motivated students beyond everyone's expectations.

The project had a large social context which helped address the *human and caring* dimensions of Fink's taxonomy of significant learning. The students' realization that they underestimated their abilities is one example of students learning about themselves (human dimension). There were multiple other opportunities for students to learn about themselves and others. As part of the course work, students interacted with many people that might have helped them understand their role as an engineer in relation to other professions. Students had meetings with various non-engineering experts from the university and local businesses. Since the sustainability engineering class was only one of many classes on campus that incorporated the garden, the civil engineering students had opportunities to interact with non-engineering students both at the garden site and indoors. For example, civil engineering students respectfully worked around ecology students setting up plant competition experiments and observed art students installing ephemeral natural sculptures on-site. Some English students writing a vision statement for the garden attended the student presentation for the civil engineering class. It is unusual for civil engineering, English, environmental science, and art students to interact toward improving a local environment, but this could be facilitated using the problem-based approach used in this and other classes.

The social context might have also helped achieve a sustainability goal of understanding local places, situations, problems, and communities. By getting to know the stakeholders and the relationship of multiple individuals to the garden, students were possibly more easily able to direct the project to develop solutions specifically for this place and for this community. Therefore, as would be expected for a sustainability project, their work was not a generic engineering solution but a place-based solution.

The collaborative and interdisciplinary nature of the project seems to have benefited not only students but also others involved. For example, a faculty member of the garden steering committee noted that she enjoyed learning about the engineering approach to solving the problem (e.g., water pressure considerations, calculations of roof area needed for sufficient water, and other technical considerations such as access to ground water, pipe expansion) which she learned was well outside the realm of her own discipline. The class gave the faculty and graduate teaching assistants on the steering committee the opportunity to interact with engineering graduate students for the first time. Since students did an analysis specifically for the benefit of the garden and ultimately the university, the steering committee and the university directly benefited from this project. Even if the university does not implement the specific watering system that students designed, the data students collected on the garden will be useful in furthering the garden efforts on campus. The faculty volunteers of the steering committee members also mentioned that they benefited from observing how this class was run. Due to time constraints and personal choices, it is a rare opportunity for a faculty member to observe another class. Yet, through their involvement in the project, steering committee faculty members were exposed to Fink's taxonomy of significant learning and other pedagogical approaches used in the class.

Future Plans to Use the Outdoor Classroom Garden in Civil Engineering Curriculum

Future plans are to develop other garden projects to be used in the sustainability engineering class. These projects can focus on a specific process or activity related to garden management and on making recommendations to make the process more sustainable. Students can continue to use ecological design principles and life-cycle assessment as primary tools for analyses. Students can, for example, estimate water, carbon, and energy footprints and can consider other sustainability indicators related to social and economic sustainability. Possible semester long term projects may be the design of a composting facility or a composting toilet on-site or analysis of the energy, water, and global warming implications of the plants and food grown on the Outdoor Classroom

Garden. Students will thus be able to continue to quantify the "sustainability" of garden activities on the University of Toledo campus and will help make the University of Toledo more sustainable.

One of the coauthors has plans to incorporate the garden in the fluid mechanics course by focusing on biomimicry as a theme. Fluid mechanics courses generally use examples from built environments. Yet, fluids are everywhere in nature, which has found multiple ways to reduce drag through geometrical modifications to structure. Engineers are gradually learning nature-based techniques and have recently begun mimicking shark skin, box fish, and humpback whale to reduce drag in swimwear, cars, and wind turbines. More recently, researchers mimicked the capillary pressure principle of trees' water uptake system to move water to higher elevations and generate electricity during this process (Borno et al. 2009). This mimicking process has to begin with observing nature. Biomimicry (inspiration and learning from nature) can be used in fluid mechanics courses to relate course content to nature. Using inquiry-based learning, students can work in teams and observe how garden organisms function in the presence of fluids. They can use these observations to develop engineering solutions for fluids-based problems.

Other faculty members in the civil engineering department have also proposed to incorporate the garden into their classes. For example, an air quality course may be modified to discuss the role of plants and soils in atmospheric carbon fluxes. Wastewater engineering and water treatment and supply courses may be modified to discuss the roles of soils and plants on water treatment processes. The reinforced concrete class may be modified to include design analysis of future construction projects (e.g., cistern placement, toolshed construction) at the garden site.

Conclusions

Previously published studies have shown the importance of using team-based, problem-based, project-based, and interdisciplinary learning in sustainability education. This paper demonstrated an example of how these approaches can be complemented with place-based learning, building sustainable communities, and interacting with the outdoors in a semester-long graduate level sustainability engineering class. Course design and course goals were developed using Fink's taxonomy of significant learning. The Outdoor Classroom Garden provided an opportunity for students and faculty to work both within and outside the boundaries of the classroom and the traditional civil engineering discipline. Students taking the course worked with the instructor, the garden steering committee, and multiple other students, faculty, and contractors to develop an engineering solution for the most sustainable way to water the garden. Working on the project, students developed multiple engineering skills including oral and written communication skills, technical skills of measurement and computer aided design, hydrology analysis, hydraulic system design and sizing, life-cycle cost, and environmental impact analyses. Students also developed a large knowledge base on a variety of topics that were not predetermined by the instructor. This paper showed that Fink's taxonomy of significant learning and a project focusing on a local outdoor living space can provide enriching and interdisciplinary sustainability learning experiences for students while providing service to the local community. However, results of this paper should be interpreted with caution since enrollment in many other classes would be greater and may potentially pose certain difficulties that were absent in fall 2009 offering of the sustainability engineering class. More research and other case studies are necessary to further evaluate the success and problems of combined use of Fink's taxonomy of significant learning and outdoor living spaces in higher education.

Appendix I: Fink's Taxonomy of Significant Learning-Based Learning Objectives for the Sustainability Science and Engineering Course

Learning objectives of this course.

Foundational knowledge:

Able to describe the following concepts to an intelligent high school student: life-cycle assessment, ecological footprint analysis, water footprint analysis, sustainability reporting, ecological design principles, LEED, Biomimicry, natural step, and energy savings.

Application:

Able to perform simple life-cycle assessment studies for a given process using EIOLCA software.

Able to critically review peer-reviewed articles related to sustainability science and engineering.

Able to conduct a literature review on a research topic.

Able to determine the problem statement and develop a science based strategy for its solution.

Able to communicate findings related to sustainable design in a typed research quality report and by oral presentations.

Integration:

Able to make the engineering, environmental, social, and economic connections that make engineering design sustainable or not (explain why an engineered system is or is not sustainable).

Identify the subsystems and their interactions within a sustainability problem use this knowledge to develop solutions to an engineering problem.

Human dimension:

Able to identify the ways in which the student's personal life affects and is affected by sustainability related problems.

Develop own work ethic so as to submit deliverables on time.

Able to discuss the role of engineers and scientists in progress towards a more sustainable society and the urgency of such a progress.

Caring:

Be interested in various sustainability problems and the connections among them.

Be interested in following up-to-date advances on sustainable solutions and assessment techniques.

Learning how to learn:

Be familiar with a number of popular sustainability related journals.

Able to interpret the quality, validity, and significance of sustainability related news and data.

Appendix II: Grading Scheme for the Oral and Written Deliverables

Technical Report Grading Scheme (out of 50 points)

Writing quality (15)

Coherence, grammar, spelling, punctuation, technical style, well developed paragraphs, appropriate use of tables and figures, appropriate labeling of tables and figures.

Project quality (35)

Summary or abstract. (5)

Problem description and objectives. (5)

Methods including modeling approach, data collection, input parameters, and other. (10)

Results and interpretation. (7)

Conclusion and recommendations. (3)

Appropriate use of references. (5)

Appendices.

Presentation grading scheme (out of 30 points)

Well organized and prepared slides (3 points).

Slides should not have too much text.

Slides should be visually appealing.

Logical progression of ideas leading to a coherent message.

Aim for a maximum of three take home message (i.e., your conclusion slide might have three bulleted items).

Explanation of problem (5)

Include who your stakeholders are. Who will be affected by the outcome of your results? Who might use your results?

Don't forget to clearly state your objectives (should have a separate slide for this).

Methods, explanation of model and modeling approach (total 6).

Explanation of results (6)

Conclusions and recommendations (5)

Oral presentation skills (5)

Face audience and not just Dr. Apul

Do not read from slides.

Appropriately project your voice.

Do not use uhm, aaa, etc.

Be clear about what message the audience should get from the slide.

Do not need to read the title of the slide.

Appendix III: Abbreviated Table of Contents of Students' Report

Watering Solutions for The University of Toledo Outdoor Classroom Garden

Table of Contents

Acknowledgments

The writers thank the University of Toledo for permission to install the outdoor garden classroom; UT Women & Philanthropy for funding the installation; and fall 2009 sustainability engineering students for their hard work on the project.

References

AAEE (2009). "Environmental engineering body of knowledge." *American academic of environmental engineering body of knowledge task force*, Summary available from: ⟨http://www.aaee.net/Downloads/EEJournalV6P1.pdf⟩ (March 14, 2010).

Ahn, Y. H., Kwon, H., Pearce, A. R., and Wells, J. C. (2009). "The systematic course development process: building a course in sustainable construction for students in the USA." *J. Green Build.*, 4(1), 169–182.

Aparicio, A. C., and Ruiz-Teran, A. M. (2007). "Tradition and innovation in teaching structural design in civil engineering."*J. Prof. Issues Eng. Educ. Pract.*, 133(4), 340–349.

Arciszewski, T., and Harrison, C. (2010). "Successful civil engineering education." *J. Prof. Issues Eng. Educ. Pract.*, 136(1), 1–8. 4

ASCE (2008). "Civil engineering body of knowledge for the 21st century." *ASCE body of knowledge committee*, 2nd Ed. ⟨http://www.asce.org/professional/educ/⟩ (March 14, 2010).

ASU (2010). "Global institute of sustainability." Arizona State University, Tempe, AZ, ⟨http://sustainability.asu.edu/⟩; (March 12, 2010)

Azuma, A., Horan, T., and Gottlieb, R. (2001). "A place to grow and a place to learn: School gardens in the Los Angeles Unified School District. A survey, case studies, and policy recommendations." *Center for Food & Justice, Urban & Environmental Policy Institute*, Occidental College, Los Angeles. ⟨http://departments.oxy.edu/uepi/cfj/publications/place_to_grow.pdf⟩ (March 12, 2010).

Barroso, L. R., and Morgan, J. R. (2009). "Project Enhanced Learning: Addressing ABET Outcomes and Linking the Curriculum." *J. Prof. Issues Eng. Educ. Pract.*, 135(1), 11–20.

Berman, M. G., Jonides, J., and Kaplan, S. (2008). "The cognitive benefits of interacting with nature." *J. Am. Psychol. Soc.*, 19(12), 1207–1212.

Besterfield-Sacre, M., et al. (2000). "Defining the outcomes: A framework for EC-2000." *IEEE Trans. Ed.*, 43(2), 100–110.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., and Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals*, McKay, New York.

Borno, R. T., Steinmeyer, J. D., and Maharbiz, M. M. (2009). "Charge-pumping in a synthetic leaf for harvesting energy from evaporation-driven flows." *Appl. Phys. Lett.*, 95(1), 013705. 5

Chau, K. W. (2007). "Incorporation of sustainability concepts into a civil engineering curriculum." *J. Prof. Issues Eng. Educ. Pract.*, 133(3), 188–191.

Chawla, L. (2002). "Spots of time: manifold ways of being in nature in childhood." *Children and nature: psychological, sociocultural, and evolutionary investigations*, P. H. Kahn and S. R. Keller, eds., MIT, Cambridge, MA, 199–226.

Cole, A. G. (2007). "Expanding the field: Revisiting environmental education principles through multidisciplinary frameworks." *J. Environ. Educ.*, 38(2), 35–44.

Cooper, J. S. (2007). "Evolution of an interdisciplinary course in sustainability and design for environment." *Int. J. Eng. Educ.*, 23(2), 294–300.

Cronon, W. (1995). "The trouble with wilderness: Or, getting back to the wrong nature." *Uncommon ground: Rethinking the human place in nature*, W. Cronan, ed., WW Norton, New York, 69–90.

Davidson, C. I., Hendrickson, C. T., and Matthews, H. S. (2007). "Sustainable engineering: a sequence of courses at Carnegie Mellon." *Int. J. Eng. Educ.*, 23(2), 287–293.

Edwards, L., and Torcellini, P. (2002). "A literature review of the effects of natural light on building occupants." *Rep.: NREL/TP-550-30769*, National Renewable Energy Lab, Washington, DC.

Everett, J. (2008). "Sustainability in higher education: implications for the disciplines." *Theory Res. Educ.*, 6(2), 237–251.

Fallahi, C. R., Levine, L. E., Nicoll-Senft, J. M., Tessier, J. K., Watson, C. L., 6 and Wood, R. M. (2009). "Using Fink's integrated course design: how a book changed our students' learning, our university, and ourselves." *New Dir. Teach. Learn.*, 2009, 43–52.

Fink, L. D. (2003). *Creating significant learning experiences: An integrated approach to designing college courses*, Jossey-Bass, San Francisco.

Fink, L. D. (2004). "Beyond small groups: Harnessing the extraordinary power of learning teams." *Team Based Learning: A transformative use of small groups in college teaching*, L. Michaelsen, A. B. Knight, and L. D. Fink, eds., Stylus , Sterling, VA, 3–26.

Hoffman, A. J., Morales, K. L. F., and Wallach, J. (2007). "Gardening activities, education, and self esteem: learning outside the classroom." *Urban Educ.*, 42(5), 403–411.

Huntzinger, D. N., Hutchins, M. J., Gierke, J. S., and Sutherland, J. W. (2007). "Enabling sustainable thinking in undergraduate engineering education." *Int. J. Eng. Educ.*, 23(2), 218–230.

Kelly, W. E. (2008). "General education for civil engineers: Sustainable development." *J. Prof. Issues Eng. Educ. Pract.*, 134(1), 75–83.

Mihelcic, J., et al. (2003). "Sustainability science and engineering: the emergence of a new metadiscipline." *Environ. Sci. Technol.*, 37(23), 5314–5324.

Moore, J. (2005). "Seven recommendations for creating sustainability education at the university level: A guide for change agents." *Int. J. Sustainability Higher Educ.*, 6(4), 326–339.

Murphy, C. F., et al. (2009). "Sustainability in engineering education and research at U. S. universities." *Environ. Sci. Technol.*, 43(15), 5558–5564.

Ozer, E. J. (2006). "The effects of school gardens on students and schools: conceptualizations and considerations for maximizing healthy develop- 7 ment." *Health Educ. Behav.*, 34(6), 846–863.

Ponsa, P., Amante, B., Rroman, J. A., Oliver, S., Diaz, M., and Vives, Josep. (2009). "Higher education challenges: Introduction of active methodologies in engineering curricula." *International Journal of Engineering Education*, 25(4), 799–812.

Quinn, K. A., and Albano, L. D. (2008). "Problem-based learning in structural engineering education." *J. Prof. Issues Eng. Educ. Pract.*, 134(4), 329–334.

Riley, D. R., Grommes, A. V., and Thatcher, C. (2007). "Teaching sustainability in building design and engineering." *J. Green Build.*, 2(1), 175–195.

RIT (2010). "Golisano Institute for Sustainability." *Rochester Institute of Technology*, ⟨http://www.sustainability.rit.edu/⟩ (March 12, 2010).

SAFSS (2010). "Michigan State University sustainable agriculture & food systems specialization." *Michigan State University* ⟨http://www.safss.msu.edu/Home/tabid/37/Default.aspx⟩ (March 14, 2010).

Savery, J. R. (2006). "Overview of problem-based learning: definitions and distinctions." Interdisciplinary, J. Problem-Based Learning, 1(1), Article 3. ⟨http://docs.lib.purdue.edu/ijpbl/vol1/iss1/3⟩ (March 12, 2010).

Segalas, J., Ferrer-Balas, D., and Mulder, K. F. (2010). "What do engineering students learn in sustainability courses? The effect of the pedagogical approach." *J. Cleaner Prod.*, 18, 275–284.

Tam, E. K. L. (2007). "Developing a sustainability course for graduate engineering students and professionals." *International Journal of Engineering Education*, 23(6), 1133–1140.

Wang, Y. (2009). "Sustainability in construction education." *J. Prof. Issues Eng. Educ. Pract.*, 135(1), 21–30.

Queries

1. Please check that ASCE Membership Grade Marks (M.ASCE, etc.) are provided for all authors that are members.
2. The Quist et al. 2006 citation is not in the references list. Please add it there or remove it here.
3. Internet?
4. A check of online databases revealed a possible error in this reference. (Arciszewski, T., and Harrison, C. [2010]) The issue has been changed from '10' to '1'. Please confirm this is correct.
5. A check of online databases revealed a possible error in this reference. (Borno, R. T., Steinmeyer, J. D., and Maharbiz, M. M. [2009]) The page number has been changed from '1' to '013705'. Please confirm this is correct.
6. A check of online databases revealed a possible error in this reference. (Fallahi, C. R., Levine, L. E., Nicoll-Senft, J. M., Tessier, J. K., Watson, C. L., and Wood, R. M. [2009]) The volume has been changed from '119' to '2009'. Please confirm this is correct.
7. A check of online databases revealed a possible error in this reference. (Ozer, E. J. [2006]) The date has been changed from '2007' to '2006'. Please confirm this is correct.