AC 2011-1335: STUDENTS AND SUSTAINABILITY: ASSESSING STUDENTS' UNDERSTANDING OF SUSTAINABILITY FROM SERVICE LEARNING EXPERIENCES

Jonathan Wiggins, University of Colorado, Boulder
Mary E McCormick, Tufts University

Civil and Environmental Engineering Ph.D. student

Angela R Bielefeldt, University of Colorado, Boulder

Angela Bielefeldt, PhD, PE, is an Associate Professor in the Department of Civil, Environmental, and Architectural Engineering at the University of Colorado at Boulder (CU). She served as the Director of the Environmental Engineering Program at CU for four years. She has taught the first-year Introduction to Environmental Engineering and senior capstone Environmental Engineering Design courses for a number of years. She is the PI on a Research Experiences for Undergraduates (REU) site at CU. Her research interests pertaining to engineering education include learning through service, sustainability, women in engineering, and ethics.

Christopher W. Swan, Tufts University

Chris Swan is an associate professor of Civil and Environmental Engineering with additional appointments in the Jonathan M. Tisch College of Citizenship and Public Service and the Center for Engineering Education and Outreach at Tufts University. Dr. Swan has also served as chair of Tufts CEE department (2002-2007) and as an officer in the Environmental Engineering division of ASEE (2001-2005). Dr. Swan's current interests lie in the areas of waste reuse, and service-based educational efforts in the engineering curriculum. Specific efforts involving engineering education concern project-based learning and service-based pedagogies their potential impacts on student learning and how these impacts may be evaluated and assessed.

Kurt Paterson, Michigan Technological University

Kurt Paterson is on the environmental engineering faculty, where he currently serves as Director of Michigan Tech's D80 Center (www.d80.mtu.edu), a consortium of 20 research, education, and service programs dedicated to creating appropriate solutions with the poorest 80% of humanity. His research, teaching and service interests focus on appropriate technology solutions that improve public health, international project-based service learning, and engineering education reform. Prof. Paterson teaches courses on creativity, engineering with developing communities, and community-inspired innovation. He has served the American Society for Engineering Education in numerous capacities, as a member of the International Strategic Planning Task Force, the International Advisory Committee, and Global Task Force, and as Chair of the International Division. He actively serves Engineers Without Borders-USA, as a chapter co-advisor, education committee chair, and lead on EWB's efforts to examine its educational impacts. He is currently leading several NSF-funded projects involving the design and assessment of service learning in engineering education. He is co-author of several recently released books, including: Measuring the Impacts of Project-Based Service Learning on Engineering Education, Engineering in Developing Communities: Water, Sanitation, and Indoor Air, and Environmental Engineering: Fundamentals, Sustainability, and Design.

Students and Sustainability: Assessing Students' Understanding of Sustainability from Service Learning Experiences

Abstract

An evolving engineering education paradigm is centered on the belief that solutions to current and future problems must consider a human dimension. Inherent to this challenge is the necessary expansion of technological solutions to encompass the social, political, environmental, and economic dynamics of systems on a global scale. Correspondingly, the theme underlying all aspects of educational reform is adequate preparation for engineers to address global problems in sustainable ways. Educators must work towards shifting engineering pedagogies to help students learn a more all-encompassing, human-centered, problem-solving approach. Across the country, institutions of higher education have undertaken the challenge of incorporating sustainability into curricula through various forms of pedagogy. However, there is little supporting evidence regarding the quality of these learning experiences, leaving the engineering education community with no robust or established way of measuring and/or comparing the efficacy of different pedagogies. What are the appropriate assessment measures for a human centered learning experience? We contend that as teaching methods shift towards a more holistic approach, assessment must evolve in parallel. Our research developed assessment instruments to measure the efficacy of sustainable engineering courses or programs. Using two complementary instruments, we will explore whether service learning has influenced students' knowledge of and motivation to practice sustainable engineering. Our rationale for this exploration rests in the experiential aspects of learning through service; rather than learning about sustainable engineering in a classroom, students are instilled with the humanistic nature of sustainable engineering through community involvement. The first instrument is an open-ended, reality-based question designed to measure students' levels of understanding of sustainable engineering. The second instrument is an online survey designed to measure students' confidence, motivation and affect in the sustainable engineering domain. In this paper, we describe the instrument development and validation, and focus mainly on the development of a rubric to track students' progressive understanding of sustainable engineering.

Background

Urgent calls to change educational systems to embrace sustainability gained worldwide attention in 1987. As stated in the Brundtland Report: "[Sustainable Development] challenges cut across the divides of national sovereignty, of limited strategies for economic gain, and of separated disciplines of science . . . The changes in attitudes, in social values, and in aspirations that the report urges [to achieve sustainable development] will depend on vast campaigns of education, debate and public participation"[1]. This report called for a change in the way we as humans interact with each other and the planet. In the years since this report, campaigns for education and public debate have occurred, albeit not to the vast extent envisioned by the Brundtland Commission. Education is a deeply critical element to achieving sustainability as it shapes our future decision makers. As the drivers of the industrial state, engineers have a significant role to play in making our societies and planet sustainable places[2]. Communities of engineering educators around the globe have recognized the urgent need for the infusion of sustainability themes into engineering education. In this same vein, a joint declaration by AAES, AIChE, ASME, NAE and NSPE states that “Creating a sustainable world that provides a safe, secure, healthy life for all peoples is a priority for the US engineering community” and that “engineers must deliver solutions that are technically viable, commercially feasible, and environmentally and socially sustainable”[3].The American Society of Civil Engineers (ASCE) and the American Academy of Environmental Engineers (AAEE) acknowledge the leading role engineers must assume in the achievement of sustainable development[4,5].

An Engineer’s Definition of Sustainability

As the call for sustainability has been established, what exactly does this entail? The study of sustainability itself has been described as a union of scholarship and practice, worldwide perspectives, and diversity of disciplines spanning natural and social sciences, engineering and medicine[6]. The Environmental Engineering Body of Knowledge defines sustainability as “a condition in which the use of natural resources and cycles in human and industrial systems does not lead to a diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment”[5]. The ASCE defines sustainable engineering as “the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base necessary for future development” [4]. As the definitions of sustainability and sustainable engineering include the multiple dimensions of our planetary existence, engineers must understand elements from the social, economic, and environmental domains and their interrelated nature[4]. Engineers must have competence in all areas of sustainability in order to successfully collaborate with experts from other disciplines and communicate with society and stakeholders in the pursuit of sustainability[5].

Current Status of Sustainability in U.S. Engineering Education

A report “Benchmarking Sustainable Engineering Education” was completed in 2008 and concluded that the inclusion of sustainable engineering concepts in engineering programs in the U.S. is widespread. Most of the courses that emphasized sustainable engineering were targeted to upper division undergraduate and/or graduate students. In some cases programs offered stand-alone sustainability courses, and there were also many courses in which sustainability had been integrated as an important theme. However, there was generally little organization to the efforts to infuse engineering education with sustainability, and the report suggested that standards should be developed for sustainability in engineering education. Another finding regarding sustainability education in US engineering schools was that such education tends “to emphasize the immediate environmental and social impacts of engineering designs”[7]. This indicates the absence of a critical long term sustainability component. The present status of sustainability in higher education has been considered as: “Although efforts are being made in pursuit of sustainability the current glut of unsustainable practices in the US and around the globe strongly speaks of insufficient progress in the pursuit of sustainability” and further, that we are in a “simmering period” of preparation for acceptance of sustainability in higher education[8].

Human Dimension in Sustainability Engineering

One important concept of sustainability is that those who are affected by the engineering designs must be involved in the process[2]. The human dimension of sustainability is difficult to define.

One source describes the human dimension in a learning context as: "learning about oneself and others… [which] informs engineers about the human significance of what they are learning. Adding the learning outcomes of caring and human dimension is critical if a balance of societal issues is to become inherent in all environmental education and practices. [This] is critical to achieving a balance of sustainability that integrates environmental, social and economic systems"[9]. This shift would entail our consideration of the entire social and human system in engineering design – "to include the entire integral community, the totality of living interests that will be affected by our choices as engineers"[10]. There is a call to advance engineering bodies of knowledge with the inclusion of this enhanced learning outcome.

Sustainability is an outcome we have mostly just aimed to achieve and further as any literature review will quickly evidence, is a concept which has been defined in many different ways. As such, we do not always have a "clear understanding and competence in the processes that have the potential to lead to sustainability." Thus learning approaches should be grounded in processes which can lead to sustainability[11]. "Research must be focused . . . on ways of promoting the social learning that will be necessary to navigate the transition to sustainability" to discover these effective learning processes for sustainability[12].

Our study examines service learning as a potential method of infusing sustainability concepts into engineering education. Service learning is a type of experiential learning that brings students in contact with real world situations, thereby providing an opportunity to learn about sustainability by focusing on human needs and accounting for real world constraints.

Assessing the Outcomes of Sustainability Education: Past Attempts

The literature reveals that assessment of sustainability concepts to date have been primarily based on quantitative measurements such as the number of students enrolled in sustainability related programs, the number of class incorporating sustainability, and other such measurements. Student surveys include campus wide surveys measuring attitudes, beliefs and behaviors of students regarding sustainability issues such as surveys available from the Association for the Advancement of Sustainability in Higher Education[13]. In "Advancing Sustainability in Higher Education: Issues and Opportunities for Research" suggestions are offered for an empirical analytical study incorporating "Pre- and post-course surveys of the sustainability knowledge, beliefs and actions of students in courses that integrate the Earth Charter in an intensive way compared with those that do not;" however no record has been found of the creation of specific instrumentation for the implementation of this study[14].

Less effort has been expended on qualitative measures of sustainability. "The production of graduates with insight into the interconnectedness of environmental issues and an ability to meet the needs of sustainable development will be best served if governments and educational institutions recognize the relevance of qualitative measures of effective learning"[15]. The Australian government has made a push for measurable curriculum outcomes of sustainability in education and higher education; however, their measurement metrics are not readily available[16]. Learning outcomes were assessed in an "Introduction to Sustainability Class" at the University of Prince Edward Island. Students' learning outcomes of sustainability were assessed based on an "extensive project and course evaluation at the end of the class" with details not provided as to the exact nature of the evaluation[17]. At a university in Hong Kong sustainability themes have been integrated into the civil engineering curriculum, with the sustainability learning outcomes evaluated via student feedback questionnaires, peer reviews, supervisor comments and employer surveys. The student feedback questionnaire was administered pre- and post- in a design project class. Sustainability learning outcomes were assessed based on the relative importance students assigned sustainability between the pre- and post-questionnaires to the other factors involved in project implementation. The peer reviews included sustainability as a measurement of project achievement – reinforcing students' belief in sustainability issues[18].

The United Nations Environment Program (UNEP) has developed a university level course for sustainability education with a goal of integrating environmental, social, and economic sustainable development issues. Instruction emphasizes social, economic, and environmental challenges in Africa. Students are given a pre-test to assess their knowledge of sustainability and a final examination at the end of the class. These examinations are graded with a rubric evaluating economic, environmental and social aspects of sustainability. Students are scored according to problem identification in each of these aspects and suggested strategies for resolution[19].

Assessing the Outcomes of Sustainability Education: Our Methodology

Our previous paper presented initial efforts to determine whether service learning experience influences students' attitudes towards sustainable engineering[20]. This paper describes the theoretical basis and assessment instrumentation of our study as well as the implementation of the final instrument assessment phase of the study, with the major focus being the development of a rubric to track students' progressive understanding of sustainability in engineering. The assessment includes both a qualitative instrument and a quantitative instrument. Students self-generate a code that allows the responses to the two assessment instruments to be linked. The instruments also ask students to self-report their level of previous involvement with course-based or extracurricular engineering service. In addition, there are other demographic questions related to students' year in college, etc. The instruments are intended to be administered in a pre- and post- format in courses where students are expected to learn about sustainable engineering. A grading rubric for the qualitative assessment was iteratively developed using sets of pre- and post-question results from spring 2010 freshman, senior and graduate level classes at Tufts University, the Michigan Technological University and the University of Colorado at Boulder. We developed our rubric to capture a wide range of answers while achieving proper inter-rater and intra-rater reliability to achieve acceptable levels of consistency and consensus estimates.

After completion of the reliability and validity verification of instrumentation, we will use the comparative data in conjunction with each individual's service learning and/or sustainable design experiences to make inferences regarding the pedagogical advantages and/or disadvantages of service learning as a means of practicing, learning, and understanding the process of sustainable engineering. The two instruments are described in more detail below.

Qualitative Assessment

The first instrument presents students with two open-ended, reality-based questions designed to measure students' levels of understanding of sustainable engineering. Students are asked to briefly describe their service learning and extracurricular service experiences. Then students are presented with two open-ended, reality-based scenarios and questions designed to measure students' levels of understanding of sustainable engineering as well as a corresponding grading rubric. The students select one of the two scenarios and are asked to respond using no more than one page and 30-45 minutes.

Qualitative Assessment: Administration

In spring 2010, the survey and essay questions were administered to freshman engineering introduction classes, senior design classes and graduate classes; most of the students were majoring in civil or environmental engineering. During all administrations, all classes were given the survey and essay question to complete on a voluntary basis except for one of the classes which received the bonus of a pizza party for completing the survey and essays. Responses for this class were much higher than those for all other classes involved. One limitation that we encountered was a low response rate; many of the students who did complete an essay question did so with very little essay content. We began the second round of instrument administration in the fall 2010. We encouraged students to make a greater effort when completing the essays and overall received more detailed responses. During the fall administration a number of classes were given the survey and essay question on an extra credit basis; however this did not significantly increase the response rates.

Quantitative Assessment

The initial quantitative instrument was used in spring 2010. After this first round of implementation, survey results were evaluated using Principal Component Analysis. Three constructs, formed around students' self-efficacy to practice sustainable engineering, were found significant. These three constructs were used as a basis for developing a revised instrument. The second version of the survey is geared towards measuring students' motivation to practice sustainable engineering. The thirty-five survey questions comprising the second instrument are structured in an Expectancy Value Theory framework in the domain of sustainable engineering, comprised of self-efficacy, motivation, and affect[27,28]. The quantitative assessment survey was intended to be administered after the qualitative instrument. It is comprised of several sections. The revised survey takes about five minutes to complete and opens with a consent form, institution attending, and code name for linkage of each survey to the corresponding essay written by each student. Section two concerns demographics: gender, age, academic status, engineering major, and learning experience. The service learning experience section asks students to check box any experience they have had in the following categories: extracurricular service-based club, service-learning course, learning experience abroad, undergraduate research, internship or co-op experience, and engineering senior/design course/capstone. Students are then asked to describe each experience checked in 1-2 sentences. Section three deals with students' confidence to perform sustainable engineering tasks and is based on a Likert scale of 0 to 100 in increments of 10. It is broken into four sub-scales of environmental, social, economic, and interacting sustainability sub-areas. Section four focuses on value for students to include sustainability in their engineering practice, including attainment value, intrinsic, and extrinsic motivation, on a 0 to 5 Likert scale. Section five deals with students' affective domain of sustainability, also evaluated on a 0 to 5 Likert scale.

Response rates for the quantitative survey instrument were much higher than that of essay completion, likely due to the relative ease of survey completion and engineering students' resistance to writing exercises. Our current survey is in final testing on a second set of pre- and post-surveys to establish acceptable consistency measures and to validate the survey constructs.

Rubric Design

Scoring rubrics have been used across disciplines and so can be appropriate tools for measuring the multi-facets of sustainability[22]. The metarubric concept indicates that there are four critical rubric traits: content/coverage, clarity, practicality, and technical soundness/ fairness[24]. Faculty at the Colorado School of Mines developed a rubric to track the progress of student teams in engineering design learning outcomes[23]. They found that their scoring rubric "provided a valuable tool for both measuring student performance [on a progressive basis] and stimulating curriculum improvement [23]." Rubrics can thus be used on a progressive basis to track students' sustainability learning outcomes throughout their education. One type of rubric - the analytic rubric – can be used to evaluate multiple criteria on separate scales[21]. Our rubric is an analytic rubric developed to measure both breadth and depth of sustainability as evidenced in the students' writing.

Scoring rubrics include detailed explanations of each of the scoring criteria so that raters can easily reach consensus on the appropriate scores. If the instruments are used for formative assessment, the text can also enable students to clearly understand their areas of weakness[22]. In this case the information can be used by engineering educators to determine areas needing improvement in their curricula to meet sustainability learning outcomes.

Rubric Evaluation Basis

Our rubric design was based on a framework presented by the United Nations (UN) in a report entitled, "Indicators of Sustainable Development: Guidelines and Methodologies."[25] The UN document provides a comprehensive and realistic set of sustainability themes and indictors, and focuses on sustainability on a global level. Indicators provide a common basis for development efforts, in this case in engineering education. While the sustainability indicators are not themselves the agents of change, they can offer insight into what sustainability efforts might be [26].

For our rubric the three pillars of sustainability – social, economic, and environmental – were used as the main themes and sub-themes originating from these categories were taken from the UN report to provide greater description of the breadth of each pillar. Pillars are further described by general indicators also taken from the report. These indicators do not provide specific quantitative targets but rather point to distinct areas of importance in sustainable development. These general indicators can be used as metrics of sustainability learning outcomes – what students should be learning about sustainability, what it means on a global scale and what it looks like. Figure 1 shows our rubric for evaluating students' knowledge of the social aspects of sustainability. Students' essays are graded based on a 0 – 6 point system. A student is given one point for each of the three pillars recognized in his/her essay (3 points maximum). Similarly, students may earn up to 3 points for considering each pillar in the context of long term stability or growth, e.g., for developing holistic, sustainable solutions.

Figure 1: Example of Rubric for Social Pillars

Social Considerations: *Actions to provide a reasonable, equitable quality of life for all.*

Themes	Subthemes	Description	Student Examples
Equity	Poverty, Gender Equality, Equal Opportunity	● Poverty eradication ● Full employment ● Social integration, equality of opportunity ● Equality between women and men ● Universal and equitable access to quality education and primary health care ● Accelerated development in the least developed countries	*Creating jobs and training people* *Caste, minority, and economic status equality,* *Business opportunities for women, social campaigns for gender equality*
Health	Nutritional Status, Mortality, Sanitation, Drinking Water, Healthcare Delivery	● Meeting primary health care needs, especially in rural areas ● Controlling communicable diseases ● Protecting vulnerable groups ● Meeting urban health needs ● Reducing health risks from environmental pollution and hazards	*Medical post, etc.* *Building hospitals, constraining disease, healing sick, preventative actions* *Sanitation and water treatment*
Education	Education Level, Literacy	● Reorienting education towards sustainable development ● Increasing public awareness ● Promoting training	*Education for sustainability, Education to promote societal growth* *Training programs*
Housing	Living Conditions	● Cleanliness ● Stability for long term ● Adequate shelter	*Building homes, improving homes, removing waste*
Security	Crime	● Achievement of a stable and secure climate	*Working with community to maintain safe living conditions*
Population	Population Change	● Stable fertility rates ● Support of rural development	*Supporting families and educating them on health and living conditions*

Importance of Common Basis for Evaluation

While one source posits that "higher educational strategies for advancing sustainability need to be developed by individual systems and institutions so that they remain locally relevant and culturally appropriate," some form of uniformity must be present in engineering education[14]. As the literature has shown, efforts to integrate sustainability into engineering education in the US are occurring on a widespread basis. However, these efforts are proceeding without coordination and a standard baseline for achievement. A tool such as the rubric we have devised could be used across engineering disciplines to evaluate understanding of general sustainability issues. Separate criteria could be used to evaluate discipline specific sustainability issues. However, discussion of engineering discipline specific sustainability issues is beyond the scope of this paper.

Conclusions

Sustainability should be a critical component of higher education, specifically environmental engineering education. Although efforts to integrate sustainability into environmental engineering education are increasing in institutions, the effectiveness of different methods has yet to be determined. Our research aims to evaluate learning outcomes of sustainability education in students' through a survey and essay question. These tools are allowing us to measure students' knowledge, attitudes, and confidence to understand and engage in sustainable engineering. We are planning to compare the results of this study based on student experience to investigate whether students with service learning experience have a deeper understanding and higher motivation to practice sustainable engineering as measured by our instruments. We believe our study is an important step in forming a common basis for evaluation of sustainability learning outcomes throughout environmental engineering education in the United States and may be applicable to other engineering disciplines as well.

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Appendix A

Engineering Challenge Questions

Please answer one following questions. Please use the full page for your response.
Question A: As an engineering consultant, you were recently put on a team for a new project, and the client is your alma mater (the university you attended). The job involves providing recommendations on all aspects of new construction on campus and on the potential renovation of existing facilities, such as buildings and dormitories. The task is particularly important given the challenging economic climate.
What major technical issues would impact your recommendations? What major nontechnical issues would impact your recommendations? What types of changes would you like to make to

address these challenges? What will be the potential impact(s) of your recommendations? What are the foreseeable consequences of implementing your ideas?

Question B: A friend of yours (who is not an engineer) has recently returned from the Peace Corp work she was doing in a small village in Tanzania. She discussed the challenges the people there were facing and asked what you would do as an engineer to improve the quality of life. What major technical issues would impact your recommendations? What major nontechnical issues would impact your recommendations? What are some examples of products or services that might you design for the community? What would be the potential impacts of these changes? What are the foreseeable challenges?

Appendix B

Figure 2: Abbreviated Scoring Rubric

Step 1 Each essay is scored based on recognition of elements of the problem. The maximum number of points a student may earn for Step 1 is 3. Identification of 2 elements in one solution suggests interdependency.

Societal Considerations	Economic Considerations	Environmental Considerations
Actions or ideas *related to improving quality of life*	*Anything done to improve, maintain or consider the economy*	*Actions or ideas to benefit or sustain environmental health.*
Education	Economic dependency	Freshwater/groundwater
Employment	Energy	Agriculture
Health/water supply/sanitation	Consumption and production patterns	Protection of wildlife
Housing	Waste management	Biodiversity
Welfare and quality of life	Transportation	Sustainable forest management
Cultural Heritage	Mining	Global climate change/sea level rise
Poverty/Income distribution	Economic structure & development	Sustainable use of natural resources
Crime	Trade	Sustainable tourism
Population	Productivity	Land use change
Social and ethical values		
Access to land/resources		
Community structure		
Equity		
Points	Points	Points

Step 2 Each essay is scored based on development of sustainable solutions with respect to social, economic, and environmental impacts. The maximum number a points a person can earn for Step 2 is 3.

Societal Considerations	Economic Considerations	Environmental Considerations
Actions or ideas *related to improving quality of life*	*Anything done to improve, maintain or consider the economy*	*Actions or ideas to benefit or sustain environmental health.*
Cultural Acceptability	Education/training for production or market growth	Long term environmental health
Sustainable agriculture	Operation/maintenance of systems	Natural energy sources
Education for sustainability	Sustainable agriculture production	Composting
Education for growth	Long term economic growth planning	
	Lifecycle analysis	
	Increased desirability/usability of products	
Points	Points	Points

Total (Maximum = 6 points):