Experiential Learning in the Civil Engineering Curriculum: Collaborations between Community Colleges, Research I Universities and National Laboratories

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Abstract

The next generation of engineering professionals must be prepared to solve complex and multidisciplinary problems in a sustainable and global context. However, based on the authors' perceptions, many university- and community college-educated engineers do not feel prepared to address these challenges because they are not introduced to these concepts during their engineering education. Faculty collaboration between Arizona State University and Mesa Community College faculty as well as Lawrence Berkley National Laboratory researchers and Laney College faculty are piloting the development of learning modules for incorporation into courses where sustainability research themes and/or active learning are not typically present. The learning modules employ active, experiential learning through team-based activities that bring contextualized experience into the classroom, allowing students at the different institutions to deepen their "real-world understanding." This paper examines the expansion of a peer network of engineering educators that facilitate the collaborative development of module sets, making it easy for faculty at research I (research extensive) universities, community colleges and national laboratories to incorporate challenges and experiential learning into higher education classrooms. The expansion of the peer network revealed that experiential learning modules and the transformation of higher education is generally met with enthusiasm and passion to create institutions that are committed to excellence.

Introduction

As environmental concerns such as climate change and energy security continue to weigh on society, the next generation of engineering students will need to be prepared to apply sustainability concepts to solve complex, global challenges. Understanding the linkage between decisions, engineering, and sustainability will become a critical component of engineering education, particularly as green technology emerges as the most important industry of the 21st century[1], and engineers are called upon to design sustainable systems within the complex problems of the 21st century[2]. As evidenced by many sustainability-related programs around the nation, educators are moving towards preparing students whom are well equipped with concepts and applications of sustainability.

Current engineering curricula face several challenges to effective undergraduate education in science, technology, engineering, and mathematics (STEM) disciplines. The National Research Council (NRC) outlines these challenges to include providing engaging laboratory, classroom and field experiences; teaching large numbers of students from diverse backgrounds; improving assessment of learning outcomes; and informing science faculty about research on effective teaching[3-5]. Several Accreditation Board for Engineering Technology (ABET) criteria additionally require engineering programs to demonstrate that students attain the ability to function on multidisciplinary teams and the ability to communicate effectively[6].

Addressing current challenges requires educators to increase their use of approaches that enhance the education of students in STEM fields. Research suggests that employing a team-based approach promotes active and collaborative learning while simultaneously advancing individual accountability, personal responsibility, and communication skills[2]. Two well-known pedagogies are experiential and active learning. Experiential learning engages students in a real, as opposed to abstract, experience[7,8]. Similarly, active learning enhances students' ability for lifelong learning by placing the learning responsibility on the learners themselves[9]. Adopting these pedagogies into engineering curricula allows educators to address students' needs via exposure and interaction with real-world multidisciplinary problems that require contextualized applications of sustainability.

Research suggests that community college educated engineers are a critical, unaddressed component in the re-casting of engineering education methodology[10]. If engineering educators aim to create courses that train students to think outside the box, connect their learning to the real world, and critically evaluate their actions and project findings, then community college educated engineers must also be afforded the opportunity for exposure to these different teaching pedagogies. Faculty from two- and four-year institutions, Mesa Community College (MCC), Laney College (LC) and Arizona State University (ASU), and researchers at Lawrence Berkley National Laboratory (LBNL) are piloting curriculum that brings contextualized experience into the classroom by collaborating to update traditional university and community college engineering courses with a dynamic mix of active, experiential learning and hands-on laboratory experiments that are infused with real-world data.

The goals of this cross-institution collaboration experience were to enhance existing activities by enabling the development of sustainability-themed learning modules for incorporation into engineering courses where research themes and/or active, experiential learning are not typically present at either the university or community college setting. These collaborations also aim to counteract a perceived misconception regarding the differences in education quality between the institutions by establishing shared community resources for which all students at both institution types can benefit. The ultimate goal of these collaborations is to attract and retain a talented and diverse set of students who are better prepared to tackle the engineering challenges of a global economy within a sustainable, multidisciplinary context. The authors of this paper reflect faculty that were or currently are at a research I university, a community college, and a national laboratory.

Research I university & community college collaboration

ASU and MCC partnered to develop active, experiential learning modules with sustainability-related themes and to promote deployment of these modules in traditional engineering courses at both institutions.

ASU is a public research university and the largest public university by enrollment, comprising more than 72,000 students. ASU offers bachelors, masters and doctoral degree programs in 16 colleges and school on four campuses within the greater Phoenix metropolitan area. Housed within ASU is the School of Sustainable Engineering and the Built Environment (SSEBE), which blends sustainable, civil and environmental, construction engineering and construction management programs, and is known for research on the connections between the built environment and human and natural systems.

MCC is the largest of ten community colleges in the Maricopa Community College District and is the largest community college in the nation, comprising more than 40,000 students, offering two-year degrees as well as transfer, career and certificate programs and is one of ASU's largest transfer providers. The Physical Sciences Department at MCC includes traditional freshman and sophomore level astronomy, chemistry, engineering, geology and physics courses. Engineering courses are designed to prepare student to transfer to four-year degree-granting institutions. MCC has a standing relationship with ASU and has contributed to collaborative development, deployment and assessment of sustainability-themed active and experiential modules.

During the 2012-2013 academic year faculty at ASU and MCC piloted a water-for-energy water footprint module to introduce students to the concept of embedded, or virtual, water (i.e. water required to generate or produce a product or service) and how their decisions, engineering applications and sustainability relate to the "real-world" global and complex issue of resource depletion today. Module implementation was piloted in one civil engineering course at both institutions for the Fall 2012 and Spring 2013 semesters, see Table **1**. MCC's courses were introductory engineering courses, which focus on teaching first-year engineering students critical thinking, computer modeling, teamwork and communication skills. They included a mix of 20 freshman and sophomore level students each semester. ASU's courses were advanced engineering courses, which focus on teaching a multidisciplinary group of students integrated and ethical tools used to design and manage engineered human-natural systems. They included a mix of 82 sophomore, junior and senior level students in 2012 and a comparable mix of 77 students in 2013. Module learning objectives and associated Bloom's levels of intellectual behavior[11] for both MCC and ASU courses are listed in Table **2**.

Table 1. Water-for-Energy Water Footprint Module Implementation During 2012-2013 Academic Year

Institution	Semester	Course Number	Course Title	Enrollment
MCC	Fall 2012	ECE 102	Engineering Analysis Tools and Techniques	20
ASU	Fall 2012	CEE 400	Earth Systems Engineering and Management	82
MCC	Spring 2013	ECE 102	Engineering Analysis Tools and Techniques	20
ASU	Spring 2013	CEE 400	Earth Systems Engineering and Management	77

Table 2. Water-for-Energy Water Footprint Module Learning Objectives and Bloom's Levels of Intellectual Behavior for MCC and ASU Courses During 2012-2013 Academic Year

Water-for-Energy Water Footprint Module **Learning Objectives** ***The aim of this module is for students to have a*** *hands-on, active interaction with concepts of sustainability and virtual water energy via experience conducting water footprint calculations*	**Bloom's Levels of Intellectual Behavior**[11]					
	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
to identify different types of electrical energy generation	X					
to conduct real world data collection, and organize data	X	X				
to recognize and explain embedded water terminology (embedded water, virtual water, water footprint, water-in-energy)	X	X				
to develop MATLAB function to solve for water footprint (MCC ONLY)			X		X	
to graph and compare the results from different online water footprint tools (ASU ONLY)				X		
to contrast differences between online water footprint tools and justify which tool(s) account most realistically account for virtual water footprints (ASU ONLY)					X	X

Water-for-energy water footprint module at MCC

Prior to the water-for-energy water footprint module, MCC students were asked to read a white paper from American Water[12] on the difference between the value of water and actual prices paid for water and to bring an electricity bill from home. The class commenced with a brief lecture covering virtual water and water footprint concepts that led to an interactive discussion of water-for-energy to engage students in data retrieving and critical thinking skills. Students were then guided through a discovery of electricity production for their residence through the use of the Environmental Protection Agency (EPA) Power Profiler website[13]. The class closed with a student-led class discussion on the different types of electrical energy production in the United States and the varying water requirements for each, and concluded with a short lecture covering Mesa and Phoenix, Arizona water supplies.

During the second portion of the module MCC students were split into groups of two to record the energy supply mix of their residency location via the EPA Power Profiler website. Students were asked to consider and explain their thoughts on electricity production in their area. They were prompted with questions regarding the primary generating source of electricity for their residency and any surprises that may, or may not, have occurred to them during this discovery. Students then were asked to document water intensity data for electricity generation by type from the lecture given the previous class period to determine the water consumption intensity per kWh of electricity for their area. With this water consumption intensity, and the total electricity used as shown on their electricity bill, students then calculated the total gallons of water embedded in the electricity used for the month. Students established a correlation between the electricity generation types, water consumption intensities, and themselves by tying in data from their own power bill and determining their own water footprint resulting from electricity use for one month. Students utilized their electricity bill to find the price per kWh of electricity to estimate a "dollar intensity" of the water embedded in the electricity. Students at MCC were tasked with putting this process into an algorithm in a MATLAB function statement so that the steps could be easily repeated for any given zip code or region.

Water-for-energy water footprint module at ASU

Prior to the water-for-energy water footprint module, ASU students were asked to read a paper on the Water Energy Nexus[14] and book chapter Water and Industrial Ecology[15] which present embodied water and expose students to the interaction of water systems to other systems. The class began with a lecture covering virtual water and water footprint concepts. Particular attention was given to the embedded water in energy and in common goods and service that they students interact with on a daily basis in an effort to engage students on a personal level. Students visited the Environmental Protection Agency (EPA) Power Profiler website[13] and reported for the class their electricity mix, which led to a discussion on different types of electricity production in the United States. The instructor guided the students through their current location's electricity mix and concluded the class with information on local water supplies for the area, as was done with MCC's classes.

For the second portion of the module ASU students were split into groups of 4 students to compare existing online water footprint tools. As a homework assignment, students tracked their personal water consumption for one week or brought in their water bill to serve as data inputs for the tools. They were asked to input the data into the tools, record the results the tool generated, and graph the results of four online tools for comparison. Students were required to break down the water footprint tool results by component where applicable and summarize the strengths and weaknesses of the tools in both reference to the ease of use and estimations for reliability and uncertainly of data inputs and results generated. Students were surprised to find that the tools did not tell the user where their water was sourced from nor did they have any region-specific information embedded in them. As an conclusion to the module, students were asked to critically review their findings and provide recommendations, if any, for which tool to use for a specific purposes, e.g. a company, an individual, a municipality, and whether or not they would recommend this tool as a reliable source of water footprint information.

Findings from water-for-energy water footprint module at MCC and ASU

Faculty at ASU and MCC hypothesized that after experiencing the active learning module, students' awareness of water requirements for the production of different commodities – electricity in particular – would increase. The faculty were surprised to learn that the concepts were completely foreign to students prior to this activity. When students were asked at the start of class how many were familiar with the term "virtual water," only one student raised his hand, and quickly admitted that had only recently become familiar with the concept through an earlier conversation with the course instructor. Moreover, many students, even those who have grown up in the area, exhibited that they knew relatively little about where their water came from. During the same activity in the spring 2013 semester, the outcome was identical. None of the students were familiar with the concept of virtual water or water footprints prior to the activity, though a couple of students had heard of carbon footprints. And although some were aware that

Arizona is supplied a lot of its water via the Colorado River, not one student raised their hand when asked if they knew about the Central Arizona Project canal – a multi-billion dollar government project which carries and delivers Colorado River water over a distance of 330 miles from Lake Havasu through central Arizona to just south of Tucson, Arizona.

An identical pre- and post- assessment survey was given to students to evaluate this module in Fall 2012 at MCC only. ASU students did not take this survey as they participated in the module prior to survey development. In summary, MCC students were asked to identify systems that require water, types of electrical energy generation, types of water involved in electricity generation, describe how they would search for water footprint data, identify their top data sources and how they would assess quality and reliability of these sources. This survey research was approved exempt under IRB protocol # PRO10010207 at The University of Pittsburgh and #1206007924 at Arizona State University to include research at Mesa Community College. Pre- and post-assessments surveys conducted in Fall 2012 did not generate informative results. The survey questions were unsuccessful in measuring whether this module helped students achieve the learning objectives outlined in Table 2, therefore faculty have rewritten the assessments and repeated the activity during the Spring 2013 semester in the same courses at ASU and MCC. The assessments were modified to assess appropriate levels of intellectual behavior, as defined by Bloom's Taxonomy[11]. The updated survey asked students to match water terms with their definition and application, identify which products consume water during the production of their final product, rate their comfort in recognizing water embedded in the products/processes that they interact with on a daily basis and make recommendations for the use of this module in future classes. One question was designed to track whether students were reading and answering the questions in their entirety or whether they were just marking answers without reading the questions fully. These updates reflect analysis of the prior semester's survey results (which were inconclusive) and helped assess whether students could define embedded resource terms such as virtual water and water footprints, in order to document the absence or presence of familiarity with these concepts prior to the module and gauged whether this module served to achieve the learning objectives previously outlined.

The authors have chosen to report on one question from the survey updates in Spring 2013. Further reporting on results will occur after collection of additional survey data during Fall 2013 semester courses. The question selected for analysis asks students to rate their comfort in recognizing water embedded in the products/processes that they interact with on a daily basis. This question was answered using a 5-point Likert[16] scale and included very uncomfortable, uncomfortable, neutral, confortable and very comfortable as possible answers.

The results of the question for both MCC and ASU courses are shown in Figure 1. The trend shown in this figure conveys a positive shift in comfort level for both schools after experience with this module. The authors recognize that ASU's results may have been skewed by exposure to lecture and embedded water discussions prior to taking the pre-survey and therefore it is not surprising that ASU students felt more confident prior to the module than MCC students, who were not exposed to the lecture material before taking the survey. However, the data suggests that participation in this module engaged both MCC and ASU students by providing an opportunity for them to derive meaning from their direct experience with personal embedded water information. This is a step towards better preparing students to make engineering decisions that include virtual water components by creating an awareness and appreciation for the significance of virtual water in fundamental commodities such as electricity. Similarly, the ability to recognize when virtual water is *not* being considered and the evaluation of potential impacts of disregarding these quantities is a important skill for future engineers charged with sustainable decision-making.

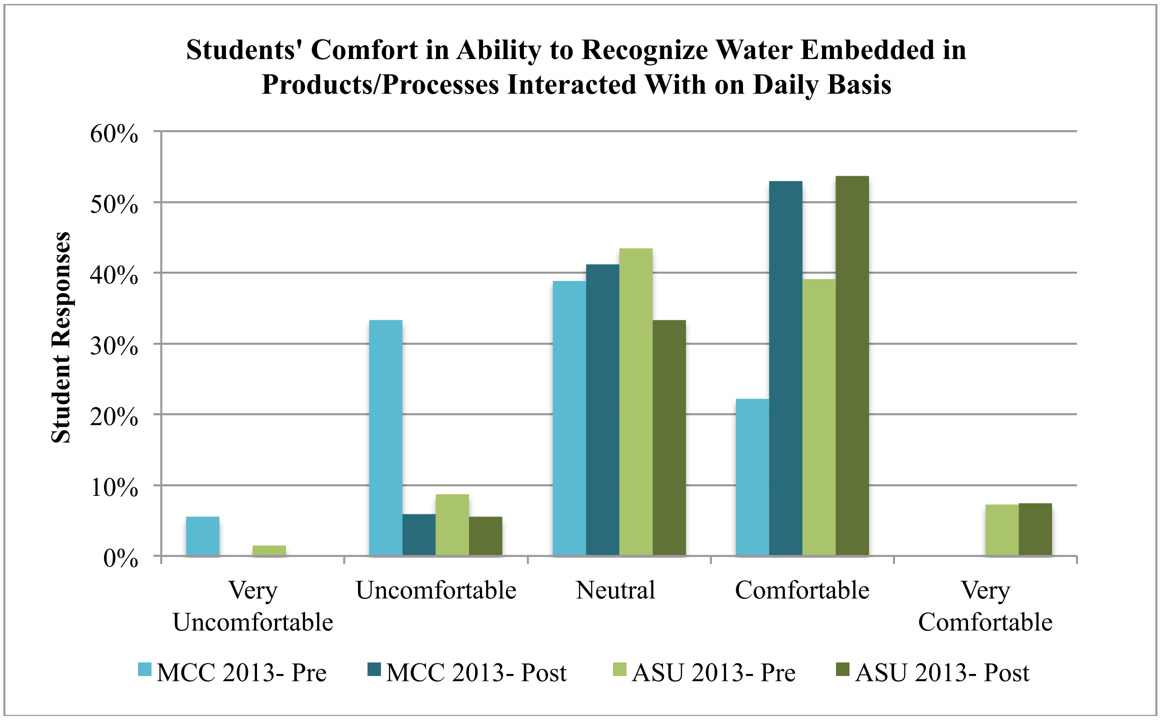

Figure 1. Students' Comfort in Ability to Recognize Water Embedded in Products/Processes Interacted With on Daily Basis depicts the trends in student responses prior to and after participating in the Water-for-Energy Water Footprint Module at MCC and ASU

National laboratory & community college collaboration

In a second example of research institution and community college collaborations to innovate in education, LBNL and LC partnered to deliver research outcomes to community college classrooms and to foster development and deployment of energy-efficient behavior in the next generation of commercial building operators and managers.

LBNL is one of twelve national laboratories managed by the U.S. Department of Energy (US DOE). It is managed by the University of California (UC) and is charged with conducting unclassified research across a wide range of scientific disciplines, including energy efficiency in buildings. LBNL's Commercial Building Systems group, in particular, focuses on action research and deployment of energy-efficiency strategies and technologies for commercial buildings. In 2010, the US DOE's Office of Energy Efficiency and Renewable Energy began to prioritize applied research, specifically seeking speed and scale deployment of research outcomes. LBNL's Commercial Building Systems group capitalized on this shift in research focus and strengthened their existing relationship with LC to cultivate LC as a deployment channel for their research findings.

LC is the largest of four colleges that comprise the Peralta Community College district, serving Northern Alameda county in the San Francisco Bay Area and comprises more than 14,000 students and offers two-year degrees as well as articulated course series that “plug and play” into four-year degree programs at California’s California State University (CSU) and UC systems. LC houses an Environmental Control Technology (ECT) program that has a reputation for excellence in training students in building systems, controls, and automation with a focus on efficiency. LBNL has a standing relationship with LC and has contributed to the ECT program with guest lectures, advisory board membership, and a host of other activities. In 2012, LC was awarded a grant from the National Science Foundation for the *Building Efficiency for a Sustainable Tomorrow (BEST) Center*.

The BEST Center is an NSF-funded center focused on developing curriculum for building technicians. LC serves as the PI for the project, and LBNL serves as a co-PI. The BEST Center supports LC’s curriculum development and acts as a library of curriculum modules for other community colleges that offer building technician training. LC works with their advisory board to identify learning outcomes for building technicians and then works with various educators and advisors to develop specific curriculum materials, including lecture powerpoints, learning exercises, assessments, and evaluation materials. LBNL provides some of these curriculum materials: deliverables from research projects become materials for problem-based learning exercises and homework assignments. Moreover, LBNL scientists, corresponding as faculty, come into ECT courses at LC to present their work, either as a lecture or as part of an in-class problem-based learning exercise. For example, LBNL prepared an Energy Information Systems Handbook[17] that illustrates how to calculate energy consumption and savings based on data from various building energy management systems. LBNL gave this to LC to use for in-class exercises. Moreover, the scientist who led the development of the handbook gave a guest lecture at LC, explaining how the handbook could be used in the course of a building technician’s daily activities, emphasizing the applicability of national laboratory research in practice.

LC provides feedback to LBNL on their materials, and helps to ensure that LBNL research is relevant to the building technician community. LBNL scientists and staff recognize the key role of building technicians in delivering energy efficiency in buildings and strive to produce research deliverables that are relevant for that community. Moreover, the BEST Center offers LBNL scientists an opportunity to present their research in a classroom setting and fosters direct communication between building technicians and building efficiency researchers. This feedback system allows LBNL to ensure relevance of their research, allows LC students to see the impact of their work as building technicians on building energy consumption, and offers an opportunity for LC students to connect with research and may expand their understanding of what a career in research, or even pursuing a four-year degree, may offer. Finally, the national BEST Center for building technician curriculum development offers an opportunity for broad dissemination of both the building efficiency research and the effective methods for presenting it to students accessibly.

The BEST Center was awarded funding in September 2012 and has been operational since October 2012. As the BEST Center is still in its infancy, evaluations and assessments of curriculum modules do not yet exist. However, the BEST Center works with two curriculum development and evaluation consultants to ensure that curriculum modules are developed with evaluation in mind and that learning outcomes can be measured. The first review meeting for the BEST Center is scheduled for May 2013 and at this point, BEST Center leadership will meet with the NSF National Visiting Committee to select a suite of LBNL research deliverables to implement in the BEST Center curriculum. Looking forward, emphasis will be placed on strengthening two-way communication between the national laboratory and the BEST Center in recognition of the role each has to play in the building efficiency sector. Specifically, we will develop a collaboration methodology that involves LBNL pushing deliverables and lecturers to the BEST Center while the BEST Center simultaneously pulls resources from LBNL and helps to shape future LBNL projects in support of curriculum needs. As the BEST Center is an established deployment channel for LBNL output, the BEST Center will identify research needs and articulate these in letters of support for proposed LBNL projects. Researchers at LBNL, the BEST Center, and on the National Visiting Committee anticipate these articulated needs will be persuasive for various LBNL sponsors, especially the U.S. Department of Energy, who remains deployment focused.

Lessons learned from educational collaborations between community colleges, research I universities, and national laboratories

This recent collaboration between research I universities, community colleges, and national labs has resulted in a number of benefits for both educators and students. Course instructors enjoy the opportunity to work together and collaborate on common themes in engineering education and expand their peer network of engineering educators. This network allows educators to test multiple teaching pedagogies and activities/modules, generating large amounts of feedback rapid improvement to best benefit the students and achieve the desired learning outcomes. The students likewise profit from the collaborations between educators. The students' exposure to different teaching methodologies allows educators to reach more students by addressing the distinctive learning styles of each student. Additionally, covering novel themes in engineering through the collective development of materials better prepares future engineers for real-world interaction with these concepts after leaving the academic setting

Despite these promising collaborative efforts to impact engineering education, barriers and misconceptions are still present. At the community college level, the majority of required courses cover engineering fundamentals; integrating real-world sustainability concepts via active learning is possible but must build on existing core concepts. One of the biggest challenges, thus, is avoiding diluting the curriculum and maintaining focus on delivering fundamentals such that students are well prepared for successive courses, and prepared to transfer to a four-year university. Community college students involved in these collaborative efforts have shown genuine excitement in having the opportunity to participate in activities that are also taking place in similar courses in a research I university setting. This reaffirms that first and second year courses at community colleges are fully preparing them to transfer to universities, if chosen, and that the efforts to collectively prepare the students at both institutions are worth the time invested in them. There is a lingering misconception about the quality of engineering education at the university and the community college settings. Student attitudes have at times suggested a belief that the courses at MCC were in some way inferior to those same courses at ASU. However, data shows that engineering transfer students from MCC graduate at a much higher rate than those beginning as freshmen at ASU. This misconception is curbed executing the same module at both institutions, despite the slight differences based on student skill level. By sharing course materials and continuing to expand the peer network of engineering educators this misconception is being addressed from both sides. There is a need for continued collaboration and transformation in engineering education such that faculty at both institutions can generate critical thinkers prepared to collectively address the complex sustainability challenges of the 21st century.

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