Enhancing Student Learning Through a Real-World Project in a Renewable Energy Courses Course

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ENHANCING STUDENT LEARNING THROUGH A REAL-WORLD PROJECT IN A RENEWABLE ENERGY SOURCES COURSE

Abstract

At the University of California at Santa Cruz, a quarter long course on renewable energy sources was complemented with a real-world team project. The course was designed for engineering and non-engineering students and did not require any advanced mathematics or physics backgrounds. The course was open to freshmen, sophomore, junior and senior undergraduate students. The course consisted of fifteen bi-weekly lectures, eight weekly laboratory sections, a midterm, and a final exam. The lecture material consisted of an introduction to renewable energy sources, energy harvesting, energy conversion, system efficiency, and energy storage solutions. The lectures consisted of instructor presentations, discussions, and in-class problem solving. In 2012, for the first time, a real-world project was introduced to a class of 50 students. In groups of five, students were asked to deliver project proposals and presentations on making the Santa Cruz Municipal Wharf operate on 100% renewable energy technologies. The students were given the actual data for electricity and gas consumption for the whole wharf for the year subdivided by month. The students were given seven weeks to complete their work and present it to the class. The group with the highest scored proposal and presentation received a chance to display their work at the newly built Monterey Bay National Marine Sanctuary Exploration Center in Santa Cruz, CA. Each group's proposal was graded by a civil engineer based on the level of investigation they presented on harvesting local renewable energy sources, assumptions, limitations, recommended technologies, strategies, regulation, economics, and recommended timeline. Each group's final presentation was video recorded and graded by a faculty member from the Sustainability Engineering and Ecological Design Program. This paper presents the results of our findings and student feedback from a short questionnaire conducted at the end of the course.

Introduction

The Coastal Energy Research Facility (CERF) Project, part of the broader collection of projects collectively known as “the Green Wharf,” is a pilot study in which the University of California, Santa Cruz (UCSC) student and faculty investigators and the City of Santa Cruz, CA (the City) are evaluating renewable energy technologies, in particular solar, and wind power generation at the Santa Cruz Municipal Wharf (the Wharf). The City is located on the central coast of California and while its climatic patterns are suboptimal for reliance on single intermittent technology for renewable energy generation, the coastal location is a prime opportunity to understand how to optimize a multiple-technology distributed microgrid. See Figures 1 and 2 for location and renewable energy resource availability details.

Figure 1 The location of the City of Santa Cruz (*top*) and its Municipal Wharf (*bottom*).

The CERF microgrid testbed project originated under the Climate Action Compact between the City, the Santa Cruz County Board of Supervisors, and UCSC in 2007. The City's Climate Action plan goal is to reduce greenhouse gas emissions 30% by year 2020 from a year 1990 baseline. This research

indicates that a fossil-fuel free Wharf will result in a savings of approximately 100 tonnes of CO₂ annually. Should renewable energy measures be implemented by year 2015, the greenhouse gas savings realized are estimated to achieve about 1% of the overall climate action goal by 2020. In addition to the ongoing CERF project serving as a pathfinder experiment to lay the groundwork for a full-scale effort to make the Wharf energy self-sufficient, it acts as an applied learning environment through which faculty, students, and the community are engaged. The data collected during the year-long pilot test is utilized in determining the feasibility of a larger-scaling up of a renewable energy system at the Wharf. The overarching goal of the Green Wharf initiative is to develop educational and planning models for integrating sustainability and renewable energy technologies into coastal communities in California.

Figure 2 California's Wind (*left*) and Solar Power Resources (*right*) [1,2]

After acquiring a California Coastal Commission conditional permit for the first off-shore wind turbine on the coast of California, a 200-watt solar panel and 1-kilowatt vertical axis wind turbine were installed on a testbed platform on the Wharf Headquarters (Wharf HQ) building as depicted in Figure 3. The energy generated by these devices powers an outlet for power tools charging and charges the batteries for an electric maintenance vehicle. Associated skid-mounted sensors also monitor bird interactions (a condition of the Coastal Commission permit) and environmental conditions, transmitting

data to a query-able server database via a web access. Specifically, the research team collects data on solar irradiance, wind speed and direction, and marine corrosion conditions to evaluate the feasibility of alternative designs for cost-effective, future large-scale renewable energy on the Wharf.

Figure 3 Santa Cruz Municipal Wharf Headquarters Building - Microgrid Testbed Location.
Screenshot from Google Maps.

The Wharf is a wood frame and piling structure extending one half mile into the Monterey Bay Marine Sanctuary. In addition to the Wharf HQ building, the Lifeguard station and other municipal service oriented structures, the Wharf consists of 27 operating restaurant, retail and adventure sport businesses. It is serviced by traditional utilities including potable water delivery, sewage collection, solid and grease waste collection, electricity, and natural gas for heating and cooking requirements. Passenger cars and commercial vehicles traverse the Wharf, paying for parking in one of almost 300 parking spots on the Wharf deck. With millions of visitors per year, the Wharf is a highly valued historical and tourist attraction in Santa Cruz. It is open to the public 365 days per year.

Engineering Education with the Real-World Project Site

The business sector cites the greatest barrier to sustainable development of a green economy is the lack of a highly trained and knowledgeable workforce pool [3]. According to the *Skills and Occupational Needs in Renewable Energy Sectors* report published in 2011 by the International Labour Office, globally “all renewable energy sub-sectors report skill shortages for engineers and technicians” [4]. Furthermore, a recent survey of undergraduate students involved in sustainability programming at UCSC during the 2011-2012 academic year indicates that of the students surveyed (N=23), overall sustainability training to gain hard skills in technology and engineering expertise is lacking [5]. According to the same study, one strength of UCSC sustainability programming is its consistent emphasis on teamwork and collaboration [5]. It is important to qualify these findings by mentioning that the majority of student respondents were non-engineering majors. Nevertheless, one effective pathway to address the gap in UCSC sustainability hard skill training is the education of sustainability engineering students of varying majors using a combination of theoretical, classroom-based lessons and real-world, team projects with a strong emphasis on teaching Science, Technology, Engineering and Math (STEM) skills. By structuring learning such that students can see the devices making the measurements and connect data patterns to place-based observations, students are better enabled to understand the scale of resource consumption and production beyond simple quantification of input and output metrics. Real-world projects do provide a tangible set of inputs and outputs, however, for students to explore in developing solutions to complex problems. Moreover, the ability to set a problem within its broader context enables students to understand why theoretically feasible solutions to real-world problem sometimes cannot be achieved and navigate the non-technical tradeoffs that often occur in sustainability-based projects, whether that be political resistance or budgetary constraints. By tasking students with developing a feasible solution to a real-world problem students gain a more nuanced appreciation for the complexities and realities of project planning, engineering, and execution.

At UCSC, points of student engagement in the CERF project include internships with graduate student and faculty team leaders and the use of the project’s data in interdisciplinary Sustainable Engineering and Ecological Design (SEED) program course curricula. The course was designed for engineering and non-engineering undergraduate students and did not require any advanced mathematics or physics backgrounds. The course consisted of fifteen bi-weekly lectures, eight weekly laboratory sections, a midterm, and a final exam. The lecture material consisted of an introduction to renewable energy sources, energy harvesting, energy conversion, system efficiency, and energy storage solutions. The lectures consisted of instructor presentations, discussions, and in-class problem solving. In 2012, for the first time, a real-world project was introduced to a class of 50 students. Following up on past sustainability curricula work at UCSC [5, 6, 7], the purpose of this paper is to illustrate the success of a seven week, real-world project whereby upper-division student teams in an advanced renewable energy course use the CERF project’s extensive background documentation and site-specific data to

determine a technically, economically, and politically feasible 100% renewable energy proposal for the Wharf.

Methodology

Over the seven weeks of the quarter, the project assignment consisted of multiple milestones and deliverables:

Week 1: Project assignment, introductory lecture, and data dissemination via course dropbox.

Week 3: First mentor consultation via Skype with each group, outline grading checklist provided.

Week 4: Each group submits outline via online course facilitation software, written feedback provided within 3 days; draft proposal grading checklist provided.

Week 5: Draft proposal due without appendices submitted via online course facilitation software, written feedback provided and discussed during second mentor consultation; final proposal grading checklist provided.

Week 6: Proposals presented to class and videotaped for viewing by instructor, mentor and SEED faculty for written comments provided to students within 3 days.

Week 7: Final proposal submitted and self and course evaluations conducted.

Introduction of team project

To introduce the assignment, background and context of the Santa Cruz Wharf, the CERF project, and the City's goals were explained to students in a guest lecture to the class by the Green Wharf manager who is a municipal infrastructure civil engineer and the mentor for the project assignment. At the end of the presentation, the project assignment was generally posed to the students as a question, *What would it take to make the Wharf operate on 100% renewable energy technologies?* The assignment was further defined in terms of inputs and outputs. Students were given inputs such as Wharf visitation figures, transportation and parking data, overall electricity and natural gas load data from the Wharf master meter billing, limited site-specific wind and solar data, the City's Climate Action Plan, microgrid testbed permitting requirements, and vendor specifications for existing renewable energy equipment installed at the Wharf. While these inputs were useful, they were intentionally incomplete and students were directed to seek out other inputs -for example the cost of energy for commercial users, and long-term, localized wind, solar, wave and tidal resource data- required to supplement the data provided in order to conduct analyses and make reasonable recommendations.

Through the seven weeks, student teams were guided by course lecture content, feedback on their outlines, draft proposals, and during mentor check-ins to prepare of a well-formatted and written 20 - 30 page project proposal and 15 minute presentation containing the following technical outputs:

- (1) Type, description, size, quantity and capacity of recommended renewable energy technologies;
- (2) Greenhouse gas emissions reductions in metric tonnes of CO₂ equivalent achieved by renewable energy technologies as compared to business as usual;
- (3) Capital, operation and maintenance costs of proposed renewable energy technologies;
- (4) Applicable regulatory policy and any proposed changes to policies required to enact proposal;
- (5) A general schedule of implementation.

Moreover, in the proposal, students were instructed to include credible references and appendices such as equipment specifications, sample data and calculations, and a delineation of each student's work contribution. The team project accounted for 20% of the overall grade for the course.

Students were grouped into ten diverse teams of five students each according to their declared major, each team balanced between social and hard science majors. The students were given two weeks to discuss their approach, appropriate anticipated technologies, distribute the workload among one another, and formulate questions for the mentor consultations. During that time, students were encouraged to “think outside the box,” have discussions with experts, be highly organized, and to document all sources of information.

Mentor Consultations

Teams were required to take part in two, twenty-minute Skype consultations with the project mentor to gain feedback and discuss concerns both early on in the project and at a later stage. Requiring the coordination of Skype consultations forced students to face the technological and communication challenges of the modern world. A mentorship requirement, although not tied to any grade, also simulated the professional relationship between junior and more senior staff with feedback spanning the technical and professional skill set development divide. With specific objectives in mind, during the first mentor consultation the mentor prompted students to give attention to the *scope* of their project. For example, how would they consider indirect energy usage not easily quantifiable such as the embedded energy utilized to treat and transport water and wastewater to and from the Wharf? How would they define the energy associated with transportation: by simply determining the fuel consumed from those internal combustion vehicles entering and traversing the Wharf or entire trips from the visitors' points of origin to the Wharf and back? The mentor also queried students on issues such as what assumptions were necessary to bound the problem, the essential consideration of the “low hanging fruit” in demand side management, expected efficiencies of proposed renewable energy technologies, and how to frame technologies that had not advanced beyond proof of concept. Further, the mentor brought the realities of costs and social resistance to ideas such as nuclear energy and off-shore wind energy farms. As expected, numerous questions surfaced during the consultations, some related to the overall approach, others requesting specific information on the Wharf and its operations. Key questions and outcomes of

the mentor consultations are included in the Discussion & Results section.

Team Proposals

Two weeks before the end of the quarter, students presented their proposals during their class time. Each group was allotted 15-20 minutes to present in front of the whole class with 5 minutes allocated for question-answer time. All group members were encouraged to speak during their presentation time. During each presentation, the students in other groups were encouraged to ask questions. The final proposals were due on the last day of the quarter, giving students approximately two weeks to modify and adjust their proposals according to the questions and concerns raised during their presentations. On the last day of the quarter, a total of nine proposals were submitted. In those nine proposal, students investigated several clean energy technologies capable of harvesting the amount of energy necessary to supplant fossil fuel usage at the Wharf. In more detail, students considered the following set of renewable energy sources: solar, wave, wind, tidal, biomass, fuel cell, run of the river, and osmotic. See Figure 4 for the number of proposals made that included each technology.

The most popular types of clean energies proposed were solar, wave, and wind with solar being the most popular. Typically, solar and wind energies are considered the most popular renewable energies. However, in this case, wave energy was the second most popular due to the unique location of the City and the Wharf and its potential. All but two groups proposed harvesting solar energy using solar panels at various locations throughout the Wharf. The most popular locations were the roofs of the buildings and canopies over parking lots. One group that did not include solar in their final proposal, but considered it, listed the following reason, “not sufficient enough in the long run to maintain renewability”. According this group’s calculations and research, the lifetime of the solar energy technology was much shorter compared to the other technologies available on the market that the group choosing as their solution.

All but three of the nine groups proposed harvesting wave energy in their final proposals. A number of groups considered the visual impact and disturbance of natural habitat by wave energy. Groups most frequently proposed harvesting wave energy through siting a wave farm a mile off the shore submerged in water. One group looked into an oscillating wave column, but did not included it into their final proposal.

In all the proposals students considered harvesting wind energy, and five out of nine ended up including it into their final proposals. Some examples of wind technologies considered included horizontal and vertical wind turbines at various locations around the Monterey Bay area such as on the Wharf and off shore in the Monterey Bay. Two proposals that ended up not considering wind energy listed the following reasons for not including it: “eyesore”, not sufficient enough in the long run to maintain

renewability, not enough wind to meet the needs, and wind energy provides less than 2 percent of needed energy.

In order to fully meet the energy requirements necessary to supplant fossil fuel usage at the Wharf, the students complemented their proposals with less popular types of clean energies, such as, tidal, biomass, fuel cell, run of the river, and osmotic. Additionally, they provided a number of examples where such renewable energies were used successfully over a long period of time.

Figure 4 Distribution of proposed renewable energy technologies in final presentations and reports.

Student Evaluation

Students were distributed evaluation checklists for each of the four graded deliverables (outline, rough draft proposal, presentation, and final proposal) in advance of each assignment due date. In addition to scores, written feedback on the outline and rough draft were also provided by both the project mentor and course grader. For the presentation, written feedback was provided by a SEED professor, each faculty member assigned to evaluate one group's videotaped presentation. Table 1 includes descriptions for each checklist component and the amount each component was worth for the final proposal and presentation deliverables.

Table 1: Evaluation Checklist for Final Deliverables

Inputs (5%): <i>Specify what data you are using to determine Wharf demands for electricity, natural gas, and transportation fuels? What data are you using to analyze and determine the feasibility of the technologies and strategies you are interested in proposing? Have you found any sources for pricing?</i>
Analyses (20%): <i>What analyses are necessary to determine renewable energy requirements? What is your approach to each analysis? What tools have you used in your analyses? Analyses should be primarily focused on technology, and perhaps to a minimal degree to policy mechanisms. Describe your steps</i>

<i>briefly either in the body of text or an appendix. Show a summary of your analysis as noted in Outputs, below.</i>
<u>Outputs</u> (5%): <i>What outputs result from your analyses? For example, you were asked to address greenhouse gas emissions in addition to the energy demand/supply balance. What can you get from each technology/strategy in terms of energy and costs/savings?</i>
<u>Assumptions/Limitations</u> (10%): <i>Define the scope of your proposal by making your assumptions explicit. All assumptions must be reasonable, transferable, and justifiable through credible sources. It is not acceptable to assume away major energy demands such as transportation. Nor is it acceptable to assume an unlimited budget.</i>
<u>Recommended Technologies & Strategies</u> (20%): <i>The Analyses will answer the question of why but here you should also answer the questions of what (how many, what type, grid tie/non grid tie), who (i.e. vendors, other applications, sources), when (i.e. in year 20XX), and where. Graphs, tables and charts work well to convey summaries of technologies/strategies/metrics as well as timelines and fiscal considerations. A minimum of one exhibit is required that shows your overall plan for technology/modifications to the wharf.</i>
<u>Regulation</u> (10%): <i>What are the overarching regulations governing the technologies and strategies you are recommending on the federal, state and local level? What permits are required? What regulates how the interconnection to the grid will occur? Mention any jurisdictional agencies.</i>
<u>Economics & Timeline</u> (10%): <i>Broadly, how will you finance the technologies and strategies you are proposing? Be thorough in describing what existing incentives exist on the federal, state, and local level? What kind of funding will you seek for the remaining non-incentive funded capital costs? Are there novel funding mechanisms you can propose? What are the general timelines for incentives, permitting, and implementing the phases of your technologies and strategies?</i>
<u>Work Contributions</u> (5%): <i>Who is doing what and why? Be sure each individual is contributing an equal amount of effort on the proposal.</i>
<u>Sources</u> (10%): <i>A minimum of 10 credible sources should be cited in a 'Literature Cited' section. C Properly cite within the body of text and in the works cited section.</i>
<u>Formatting</u> (5%): <i>Please be certain your draft includes a Table of Contents, flows logically, and has been proofread. Moreover, please ensure each person in the group is listed along with the group number on the first page. Also, ensure your sources are properly cited according to MLA or other standard. Last, be certain to include attachments of any appendices.</i>

Checklist Rationale: The components for each graded deliverable were developed to represent key components of an engineering consultant proposal to a client. “Analyses” and “Recommended Technologies and Strategies” (40% of total score on all deliverables) were weighted most heavily and logical analytical process was emphasized over “correct” outputs in terms of energy generation and greenhouse gas emissions. “Regulation” and “Economics and Timeline” (worth 10% each for all deliverables) were of secondary importance to the technical aspects of the assignment. To force teams

to delineate clear workloads for each team member, credit was given for inclusion of a description of each student's work contribution. Engineering curriculum designers often struggle to include meaningful writing assignments in undergraduate programs [8], yet scientific writing is a highly valued skill in the engineering sector [9]. In their teaching experience, the authors have observed that students often are challenged by writing assignments hence the inclusion of the checklist requirements to prepare a logically flowing and well-written final proposal with proper formatting and appropriate citation of credible sources. It was highly suggested that groups perform peer editing and utilize the on-campus writing tutor program.

Discussion & Results

Consultations & Evaluations of Intermediate Deliverables

Notably, student teams that fully participated in and engaged with the mentor during the consultations were correlated to higher overall scores on the final presentation and proposal. It was unclear why some teams chose not to participate in this required activity. Mentorship is a key facet in the initial career stage for post-secondary engineering graduates particularly those who pursue Engineer-In-Training certification, a prerequisite for Professional Engineering licensure.

Evaluations of Final Presentations & Proposals

Teams were required to analyze not only the technical aspects of the assignment but also to consider the economic and political viability of their recommendations by preparing cost estimates with rebate offsets, summaries of policy and permitting requirements, and making note of the potential for social acceptance. Students were not given a budget for their projects but rather were instructed to keep the proposal's estimated cost reasonable. Despite discussions with the project mentor on this directive, it was clear during and after the proposals were prepared that students were not cognizant of what a "reasonable" budget entailed. In reflection, the authors agree that student exposure to the varying scales of cost associated with different renewable energy technologies could be presented during the lectures and may result in better performance in this area.

Through consultations with both the project mentor and course instructor before and after intermediate deliverable preparation, improvements were observed in each team's subsequent proposal iteration. Raw final scores for the proposals ranged from 51% to 84%. Figure 5 displays the median and range for teams' performance on each grading checklist criteria. As indicated by a mean score of $m=14$ in the "Recommended Technologies and Strategies" component, teams were, in general, able to effectively describe and apply renewable energy technologies to the Wharf, and to a lesser degree, teams were able to conduct reasonable analyses to support these recommendations. As expected, teams with higher mean scores in both the "Recommended Technologies and Strategies" and "Analyses" components

prepared a much stronger proposal with a higher likelihood of feasibility than those who scored lower in both components.

An unexpected outcome was a low average score in the “Assumptions and Limitations” component as much emphasis was placed on this both early stage and over the duration of the project. Students, in general, also struggled to some degree with presenting their inputs and outputs in a logical fashion. Failure to include adequate timelines, discussion of regulations and sources by several groups lowered the overall average for each of these components. Should this experiment in real-world team projects continue in the SEED curriculum, the authors suggest giving consideration to more student exposure to crucial project framing components like scheduling, regulation and policy, and the careful identification of the sources upon which work is based. Both manual “back-of-the-envelope” and more sophisticated spreadsheet-based example calculations for conceptualizing different technology sizing would also be useful to guide students. Most teams were credited most to all of the points available for specifying their individual work contributions and properly formatting final proposals.

Figure 5 Teams' Performance on Final Proposal Grading Checklist Criteria

Results of Student Assessments of Team Project

A total of 24 students completed the end of the quarter questionnaire. In the questionnaire, the students were asked to respond to a series of questions related to the group project and the class overall. One of the questions inquired, “How would you describe your experience working as a team on the group project.” Responses from students include:

- “It was a good experience to work in a group.”
- “I liked working as a team. We really learned so much from each other.”
- “Experience with the group is great because everybody has their own ideas and that made it easier for people to contribute.”
- “Fulfilling and challenging”

Additionally, students were asked to provide feedback on the question, “What were the unexpected challenges in the group project?” A few students responded with the following comments:

- “To come up with a plan.”
- “Analyze data”
- “Finding the right technology for the proposal”
- “Contacting the correct people and looking for the right information”
- “The unimaginable load of data and information to sort thru and make a realistic proposal”

Moreover, a number of students provided negative feedback in regards to formation of groups. As mentioned previously, the students were assigned to diverse groups based on their declared major. This prevented a number of students from working with friends from the same major. The authors will be addressing this issues in the future iterations of this project by allowing several students with same majors contributing to the same group.

One of the challenges of practicing engineering is the ability to research and find appropriate technology to meet the needs of the task at hand. Overall, the real-world project addressed several Accredited Board for Engineering and Technology (ABET) criteria for student outcomes, specifically,

- (a) an ability to apply knowledge of mathematics, science, and engineering;
- (b) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economics, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
- (c) an ability to function on multidisciplinary teams;
- (d) an ability to identify, formulate, and solve engineering problems [10].

Conclusion and Future Work

As an experiment in integrating real-world problem solving into the classroom, the project proposals and presentations on making the Santa Cruz Municipal Wharf operate on 100% renewable energy technologies facilitated student comprehension of technical and non-technical considerations motivating and impeding progress toward the City of Santa Cruz’s Climate Action goals. This project is translatable, however, to any municipal or private landscape where data on resource consumption is monitored and available. Coordination with local climate action planning commitments and actions adds a layer of complexity to this real-world project.

In future iterations of this project assignment, the authors recommend changing the grading checklist to a rubric style with sample components of varying quality for students to reference. The authors also

suggest providing a sample outputs section including a timeline, cost estimate and tabular summary of energy consumption, production, and greenhouse gas emissions. Alternately, exemplar reports from past project sites could be utilized to demonstrate instructor expectations for the level of quality, and breadth and depth of analysis required. The authors will experiment in future iterations with assigning a set budget to students to provide more structured boundaries to the assignment. The authors also recommend the SEED consortium give consideration to training students on ancillary engineering skills such as cost estimation and schedule preparation as part of their overall sustainable engineering education. Moreover, in order to make gains in the effectiveness of students' technical writing, it is encouraged that future instructors of the course require peer editing and/or writing tutors for the final proposals as research demonstrates the efficacy in this modality [11]. Additionally, a Likert scale will be utilized in the pre- and post-project questionnaires to better assess student learning outcomes in future iterations of this project.

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