Novel Collaboration between Engineering and Geosciences to Design a Green Power Station for Field Camp: A Case Study

Abstract

One of the Department of Systems Engineering's capstone projects was to design a portable sustainable power generation unit to support the Department of Earth Sciences' Geology Field Camp. The team of electrical and mechanical engineering students worked with the faculty of Earth Sciences to develop specifications. The design had to fit within the existing trailer without major modifications to the trailer. The final design housed the battery pack in a tongue-mounted box on the trailer with water proof outlets to charge devices. Four solar panels were connected through keyed connectors to the box to work with the recharging system to recharge the batteries. A stand was designed to hold the solar panels and allow rudimentary sun tracking. In a subsequent mechanical design course, the stand and mounting configuration were redesigned to make them easier to use and improve functionality.

Introduction

Many approaches to improving engagement in engineering curricula have been studied ([1], [2]). Active-learning, problem-based learning, project-based learning, and service learning are established techniques to enhance learning in an engineering context ([1]). A capstone design project, by its nature, involves a complex, freeform project without a known, well-defined solution ([3]). This is a hallmark of project-based learning (PBL). The peer-interaction of a design team requires students to evaluate alternative solutions to each problem.

Involving a client in the engineering design process brings in elements of service learning. It provides a need for the design team to take responsibility for their learning. It engages social responsibility ([4], [5]), especially if the results of the project will help an underserved population or provide improvement in a societal need. In these strategies, the instructor is a crucial element to facilitate the learning, to hold the students accountable, and to guide the students to the course learning objectives. By engaging clients within the academy, clients who are engaged in fostering learning within their own student populations, a richer educational experience can be developed.

Figure 1. Tongue-mounted power distribution box

In Fall of 2016, the Capstone Design course for UA Little Rock's Systems Engineering department explored a client-centered approach to problem definition. The capstone team selected a project to develop a Green Power Station for the Earth Sciences Department's trailer, which is used in its Field Camp experience. The final power station had four solar panels that plug into a tongue-mounted power distribution box (see Figure 1). The power distribution box allows a variety of devices to be charged from a selection of standard ports (USB, AC).

The mechanical design of the panel 'storage for transport' section was two aluminum frames, each containing two panels. A minimal tripod system was supplied to work with these panels. The storage for transport was a wooden box. In the Spring of 2017, Systems Engineering's mechanical design class redesigned the storage and mounting configuration to more rigorous specifications. The resulting design combined the panels into a folded configuration for transport (see Figure 2) with a tripod that mounted in the center of the panel frame (see Figure 3). The tripod had two angular adjustments to allow the panels to be pointed at the sun and manually adjusted to track the sun. This configuration was chosen to eventually allow the tracking to be done automatically by a control system.

The Need: UA Little Rock's Field Camp

Geology Field Camp, for most BS Geology programs, is a 6-week, off-campus, field intensive, hands-on summer course. Students apply what they have learned in the classroom to think critically and solve problems in three dimensions and at real world spatial scales. Research suggests that both cognitive (knowledge and skills) and affective (emotional and attitudinal) learning result from these experiences ([6], [7], [8]).

Most field camps stay at university-owned field stations, in university/college dormitories, or in other group lodgings. Technology and creature comforts can be integrated; however, this also adds significant costs to the course. The UA Little Rock Department of Earth Sciences' BS in Geology program was no exception. While a field camp course was required for majors, the faculty did not teach this course and the students had to take this course through a different university. The 6-week time frame and the extra cost of paying for room and board (on average $3000 - $5000 in addition to regular tuition and fees) was a barrier to degree completion for many of UA Little Rock's non-traditional students.

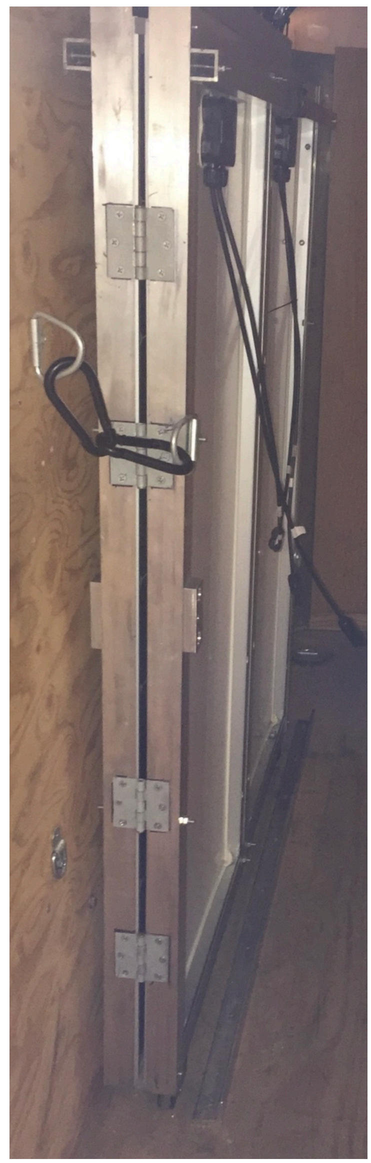

Figure 2. Solar panels rigged for transport

To meet the needs of this student population, a two course series was developed. The first course, Field Geology I, is taught on-campus during spring semesters and covers the basics of geologic field methods. The second course, Field Geology II, is an intensive 3-week Field Camp taught during July in New Mexico and Colorado.

The Field Camp is self-contained and mobile. Students and faculty travel together and stay in campgrounds the entire duration of the course. Travel is by 12-passenger vans towing two utility trailers. The trailers contain group gear: field "office" work tents, kitchen equipment (camp stoves, propane tanks, food) supplies, field instruments, and personal gear (clothing, camping equipment). The individual student cost for Field Camp is about $800 in addition to regular tuition and fees and the cost of camping supplies.

Figure 3. Tripod for solar panels

During the camp, students complete five projects in geologically significant locations. For each project, students make and record observations and collect, analyze and interpret geologic data. Final products are paper-based: maps, cross-sections, and written reports. These are all done by hand because most of the campsites are without power.

Traditionally, field geology instruction has included the use of paper maps, a notebook and a few mechanical tools (rock hammer, Brunton compass and hand lens). However, recent advances in technology (mobile devices, efficient apps, the ubiquity of digital data sets and mobile connectivity that can be utilized on the fly [imagery, GPS, GIS]) and changes in the profession from traditional geology to applied geology have made access to power a necessity. While this transition to use of technology has been smoother for many field camps because they are based at a research stations or university dorms or lodges with access to generators or the power grid, it has remained an implementation challenge for many mobile, tent-camping based field camps that have limited access to power.

The Curriculum: Capstone and Mechanical Design

The first design iteration was performed in the Systems Engineering senior capstone design sequence. The first semester of this sequence was a problem-definition process, which ended with a budget a design specification and a preliminary design. The second semester involved final design, construction and testing. The Systems Engineering capstone mixed seniors with training in electrical engineering, computer engineering, and mechanical engineering.

The second design iteration was performed in the Mechanical Systems Engineering junior mechanical design course. This course was a one-semester long class with a major design project due at the end of the semester. It consisted of mechanical engineering students. Consequently, the design was limited to mechanical elements. As a one semester course, the time-frame for the design process was compressed relative to the capstone sequence.

The novel feature of this process was the integration of a client into the design process. Many design courses focus on problem definition in the abstract, without a client or with a client that interacts through the course instructor. By using an on-campus client (Earth Sciences faculty), the students are able to engage in a problem definition phase that involves direct communication throughout the process with an end-user. The client is present at the completion of the project to provide direct feedback on the fidelity of the design to the agreed-upon specifications.

Description of the Process
At the beginning of the first semester of the capstone design sequence, the engineering design team contacted the Earth Sciences Department to learn about their requirements. The Earth Sciences faculty explained that they needed a system for charging smart devices and laptops in the field, which led to an estimated daily energy usage need of 1.6 kWh. The system had to be maneuverable by two people, and it had to fit on the front of their travel trailer.

The requirement of fitting onto the tongue of the travel trailer was an example of the back-and-forth interaction between the design team and the client. In this case, the original design was going to be stored inside the trailer; however, the trailer space was very precious, and the negotiation of the space claim led to an external solution. Since the trailer could not be permanently modified, a tongue mount box became a viable compromise solution. The client had to relax the earlier specification in which the system could be mobile in order to recover space in the trailer. This solution had the added benefit of placing the heavy battery bank in front of the trailer axle to improve stability for the towing vehicle.

This part of the process was frustrating for the engineering team, as the easy solutions (drill holes in the side of the trailer for mounting) were rejected. The team had to provide a number of alternative solutions, which helped both the engineering team and the client determine the actual specifications for the project.

The engineering team researched commercial solutions to this problem. The JASPak 300 Solar Generator provides 1.8kWh of storage and 300W charging capacity for $4,899.00. The final Green Power Station provided 3kWh of storage and 400W charging capacity for $2,424.00.

After the original design was deployed, the client provided feedback on the pros and cons of the station. The energy requirement was exceeded, although the expectation is that, with available charging power, the energy usage will increase.

A number of problems with the mechanical systems were present, and the client agreed to work with the mechanical design class to resolve those. The second iteration of the design proceeded similarly to the capstone experience. The mechanical engineering students met with the Earth Sciences faculty (see Figure 4) to measure the space and determine the requirements on storage and transport.

The shortened time-line for completion of the mechanical design increased the burden on communications and illustrated a needed change for future interactions. Formal, scheduled communication is necessary to ensure that all parties are available to discuss the problem. Written agreements on specifications are essential.

The client does not usually have a completed specification to which the engineer will design a solution. It is the engineer’s task to work with the client to determine a specification that both parties agree will be satisfactory.

In an educational environment, time spent on communication and problem development is time taken away from detailed design. In both capstone and mechanical design classes, the design teams had difficulty developing a formal specification that would allow them to begin the design. In several cases, the design team would propose a solution to the client, and discover that some constraint rendered their design to be unfeasible. This is a normal lesson in engineering design; however, without a client, the only measure of an unsatisfactory outcome is an aggregated grade that contains many components, and the lesson is obscured.

Once the specification was completed and design drawings produced, the students built the design (see Figure 5) and installed the design in the trailer.

Figure 4. Mechanical Design students meeting with Prof. Beth McMillan to work out design specifications.

Description of the Product

Solar panels are currently playing an important role in energy solutions from small calculators and toys to off-the-grid building power ([9]). Solar power products are leaving the explosive growth stage and becoming a mature technology. The components of a solar power system are the solar panels, a charge controller to adapt the intermittent solar power to a steady controlled current to charge batteries, a battery bank to buffer the intermittent solar input to the power electronics, and power electronics to provide steady DC and AC power to the load.

The market is flooded with a variety of power electronics (centralized inverters, micro-inverters, power optimizers, buck and boost converters and DC-AC inverters) ([10]) and solar panels (amorphous silicon {a-Si}, cadmium telluride {CdTe} and Copper Indium Gallium Selenide {CIS/CIGs}) ([11]) to suit many different emerging applications. To correctly select a solar panel, the available space must be determined, since the power produced is correlated to the panel area exposed to sunlight. A solar panel generates an average of 8-10 watts per square foot.

Lead acid batteries are the most economical and efficient product for large power storage due to easy access and cost. Lead acid batteries are a mature technology, and replacements are ubiquitous. Prices range from $50.00 to $400.00 for 100 to 200 amp-hour capacity. The most commonly used battery for solar power is the Lithium Ion type. For the same energy storage, the Lithium Ion battery typically costs $700.00 to $1500.00 ([12]).

Charge controllers and power electronics are a booming industry. As the use of solar technology has increased, economies of scale are driving the price of the electronics downwards.

Research is being conducted into algorithms controlling the charging and discharging of batteries. The most common algorithms are called Maximum PowerPoint Tracking [MPPT]. MPPT utilizes a control system that will maximize the power when the voltage changes due to the solar panels unique variable voltage. When clouds move across the sky, they cast shade on the panels causing the voltage to reduce. With an MPPT device, the batteries are always receiving maximum available power ([13]). The sun moves in a parabolic trajectory across the horizon, which creates an optimal window called as peak sunlight. The system will provide 1.8 kWh for every five hours of peak sunlight.

The Green Power Station consists of four 100 watt solar panels with an optimum operating voltage of 18.9 volts. Energy from the solar panels is routed through a MPPT, which optimizes the charging stages of the battery bank. Auxiliary charging devices can be used to charge the bank while the towing vehicle is connected using the vehicles alternator via a RV plug. The system is chargeable through standard US residential power (120vac, 60Hz) using a Panel Mount Power Supply that converts AC to DC. The battery bank consists of two 6 volt Deep-Cycle Flooded Trojan T-105 batteries connected in series. Together they can supply 200 amp-hours at 12 volts.

A ventilated tongue box is used to store batteries, inverter, MPPT, and other electrical components. A waterproof receptacle is mounted on the outside of the box providing 2000 watts of AC power. A USB strip is added to the inside of the box. This setup gives the user more charging options for electrical devices and will provide adequate power for the summer months.

The solar panels are connected to the tongue box during operation at camp. The tongue box sits on the front of the trailer with the ability to be removed for the safety of the equipment and the maneuverability of the trailer (see Figure 1).

The Green Power Station is designed to allow for upgrades. Adding a second box with inverter, batteries and sufficient solar panels the system's capacity can be doubled. The extra solar energy can be channeled through the existing MPPT charge controller. System capabilities will reach 5.4 kWh.

First Test of the Green Power Station

In summer of 2016, the Earth Sciences Field Camp tested the Green Power Station in the Needles Mountains in Southwestern Colorado (see Figure 6). The battery pack was attached to one of the trailers with the mounting system provided, which worked effectively on the multiple unpaved roads that the trailers were pulled over. The group stayed at Molas Lake Campground near Silverton, Colorado for the final two weeks of the course, and the battery was used almost every day to charge cell phones, tablets, and laptops, as there was no power available at the campsites. Even with this consistent use, the solar panels were not set up until halfway through the last week at the campsite. The batteries were nearly completely charged in less than a day,

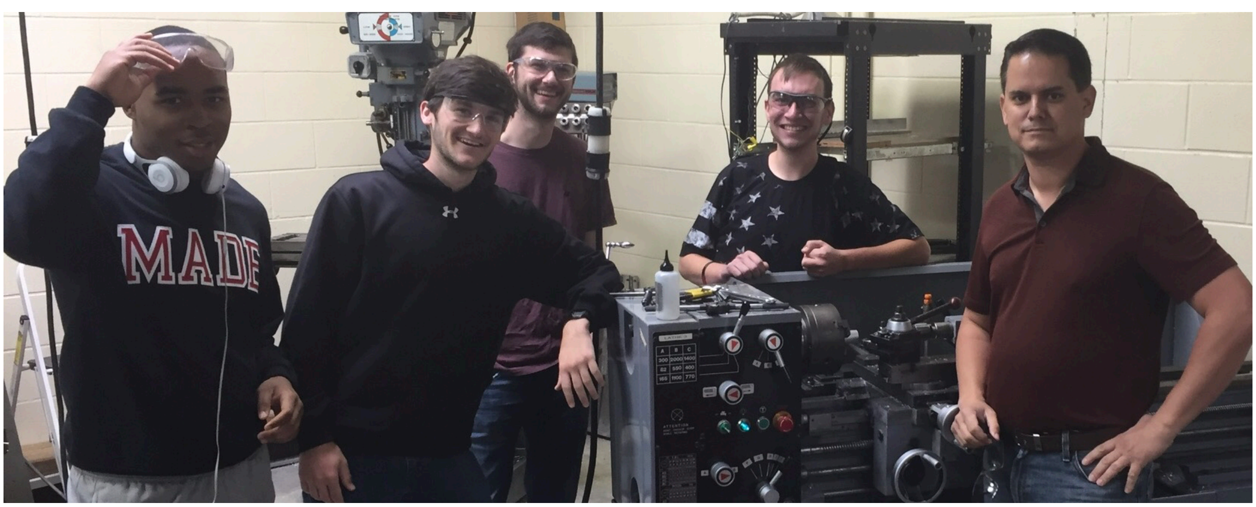

Figure 5. Tripod Design Team finishing fabrication in the UA Little Rock Student Shop

despite cloudy weather.

The students utilized iPads in the field to collect data and make measurements, supplementing the paper-based projects. The Earth Sciences department plans to use the iPads and more technology (computer and scanner) in the field during Field Camp in 2017, utilizing GIS capabilities, GPS locator, and field measurement apps. With the ability to charge our electronics, we are able to incorporate more information to aid the students in their projects.


Figure 6. Trailer and panels deployed at Field Camp

Needed Improvements
Based on experience with the Green Power Station, several improvements were suggested. The transport and protection of the panels could be improved. The panels are heavy and bulky and carrying them from the trailer to the deployment site required some strength. The container for the panels was a wooden box, which took up space in the trailer. Streamlining this containment would free space and reduce weight.

Placing the panels on the ground was not ideal. The angle between the panel and the sun was fixed by the height of the tripod. The panels were set up in the morning and angled to catch the most sun throughout the day. Automatic solar tracking would improve the amount of solar energy captured by the system.

Conclusions
Client interaction in problem definition benefits student learning in design. The results of the collaboration between Systems Engineering and Earth Sciences has yielded a design that enhances the Field Camp experience and has improved the learning in the engineering design classes.

Engineering programs can form beneficial partnerships with other campus programs, such as physics, geosciences, and chemistry, to use their design skills to solve problems in power, measurements, etc. These collaborations allow the university to use its limited resources to enhance the learning outcomes in both the design programs and the programs being served with enhancements.

Future Work
Even though the design has been a success through two iterations, there is still room for further improvements. Based on the summer 2017 Field Camp feedback, the design will undergo another (hopefully final) revision either in the 2017-18 capstone course or the 2018 mechanical design course.

This collaboration has shown positive results for the UA Little Rock campus. As word has filtered through various departments, there have been further problems proposed for either mechanical design or for capstone.

The next design iteration needs to formalize the process whereby client and design team interact, so that the communication of requirements and design can function more smoothly. Formal, scheduled communication (design review) with all stake-holders will take place. An initial design review will be held at the time of formalizing the budget, and a preliminary design review will be held prior to fabrication.

A written agreement on constraints will be instituted between the design team and the client. Space claim, weight, acceptable modifications to facilities, and other critical constraints will be developed and adhered to.

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