AC 2008-161: MULTIDISCIPLINARY DESIGN OF STUDENT PROJECTS IN DEVELOPING COUNTRIES

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MULTIDISCIPLINARY DESIGN OF STUDENT PROJECTS IN DEVELOPING COUNTRIES

Abstract

The challenge with EWB-USA project design has been to reach the proper balance of student-led creativity and learning, collection of data, and adequate expert review. Collection of data in a developing country has logistical barriers that are sometimes frustrating. Furthermore, international travel is expensive, and much of the funds raised go directly into getting the students there. Therefore, collection of data on the preliminary site assessment trip is critical and must be thoroughly planned. This paper explores the process and initial results of using an International Project Development (IPD) flowchart developed by the team to map out tasks associated with four project modules requested by a local NGO (the client) in the Bajo Lempe region of El Salvador. La Coordinadora (LC) is a peasant-run cooperative of eighty-six (86) villages that is seeking to better the lives of their people. The projects requested by the LC have been separated into four modules for the project team:

- solar energy - solar panels for backup power to office computers and equipment
- wind energy – assessment of wind resources for organic farming irrigation and a water pumping station
- hydraulics - water distribution system from a cooperative water treatment plant to additional villages on the peninsula, and
- sustainable architecture – green building design and layout for a rural tourism project.

Each of these technical modules was approached in the same manner using the IPD flowchart. Students signed up to join a module design team based on their degree specialty and/or their interest. The project flowchart includes initial brainstorming by the larger project team, preliminary design by the smaller module design team, a presentation of the initial design to the larger group with a group discussion, a group meeting with an "expert" to get his/her comments on the initial design, revision of the design, brainstorming by the larger group on sustainability issues, and a compilation of data gaps to be collected by the student travel team on the site assessment trip. In essence, the process is an iterative 3-way dialogue between the large group (10-15 students), the module design group (2-4 students), and a recognized expert. The process encourages deep learning as students actively engage in creative conceptualizing, teaching each other from general engineering principles and from their own disciplines, and interaction with a professional. Even though only a subset of the students will travel to the host country, all of the students on the project team have a sense of being involved with the site assessment planning and are invested in the project from the point of view of their chosen discipline. The IPD adventure is one that gives the student an actual engineering experience while engaging his/her passion for the social good.

Introduction

Student-led international engineering projects can be both exciting and educational. Projects with Engineers Without Borders-USA (EWB-USA) offer the student an experience that is technically stimulating and immensely rewarding as its impacts become realized in the lives of the members of a developing community. EWB-USA is a non-profit humanitarian organization established in the year 2000 to partner with developing communities worldwide in order to improve their quality of life. This partnership involves the implementation of sustainable engineering projects, while involving and training internationally responsible engineers and engineering students[1]. Engineering projects are initiated by the host community and must be supported by a local qualified non-governmental organization (NGO). EWB-USA projects stress the need for engineers to contextualize, i.e., to understand a project from the perspective of the host country and to "gain experiential knowledge about social, cultural and environmental issues by living the lives of the inhabitants in their work locations"[2].

The challenge with EWB-USA international project design has been to reach the proper balance of student-led creativity and learning, collection of data, and adequate expert review. This challenge has several major components. First, collection of data in a Third World country has logistical barriers that are sometimes frustrating and often prohibitive – language differences, difficulties in obtaining visas and proper inoculations, irregular or inadequate phone and computer infrastructure, and cultural differences regarding work pace and style. Second, international travel is expensive, and much of the funds raised by the students go directly toward getting the students to the project location. Therefore, collection of sufficient data on the preliminary site assessment trip is critical and must be thoroughly planned and efficiently executed. The coupling of data collection and design revision is easier and less expensive to do before students ever travel to the project site in the host country. And finally, because the students are (understandably) novices in engineering design, an expert review process is critical for both the success of the project and the reputation of the organization. When this review comes from outside academia, e.g., from a vendor or consultant, the review has an added educational component by introducing students to other facets of their anticipated profession.

The purpose of this paper is to explore the process and initial results of using an International Project Development (IPD) methodology to map out tasks associated with four project modules requested by a local NGO in the Bajo Lempe region of El Salvador. The methodology is presented here as a tool to minimize the effects of logistical challenges in international work and to maximize a student's deep multidisciplinary learning with his/her peers.

The General Engineering Program

All entering engineering students at this university begin in the General Engineering Program (GEP). The two primary objectives of the GEP are to provide students with a sound academic preparation for engineering study and to give them an opportunity to explore various engineering fields. Most students spend two to three semesters in this core curriculum as they learn the basic tools and fundamentals of engineering[3] while being introduced via departmental presentations to the various engineering disciplines that are available on campus. As part of its overall mission, the GEP offers general advising, career counseling and engineering education.

Students who leave the GEP and choose NOT to enter an engineering discipline are asked to complete an exit survey which includes both closed- and open-ended questions. Exit surveys collected over a six-year period were compiled and analyzed in another study[4]. Based on written comments, the surveys show that some capable students left engineering because they (1) did not see the value of fundamentals courses for a later discipline (6/400), (2) did not understand the diversity of career options in engineering (11/400), and/or (3) did not recognize the humanitarian value of engineering as a profession (3/400). It is the hypothesis of this author that engagement by freshmen and sophomore students in EWB-USA projects that are multidisciplinary in nature and that demand deep learning will improve engineering persistence and retention in otherwise qualified students.

Because of time and personnel constraints, some necessary characteristics of engineering are inevitably given only brief attention in the threshold program. Three of these characteristics are given below:

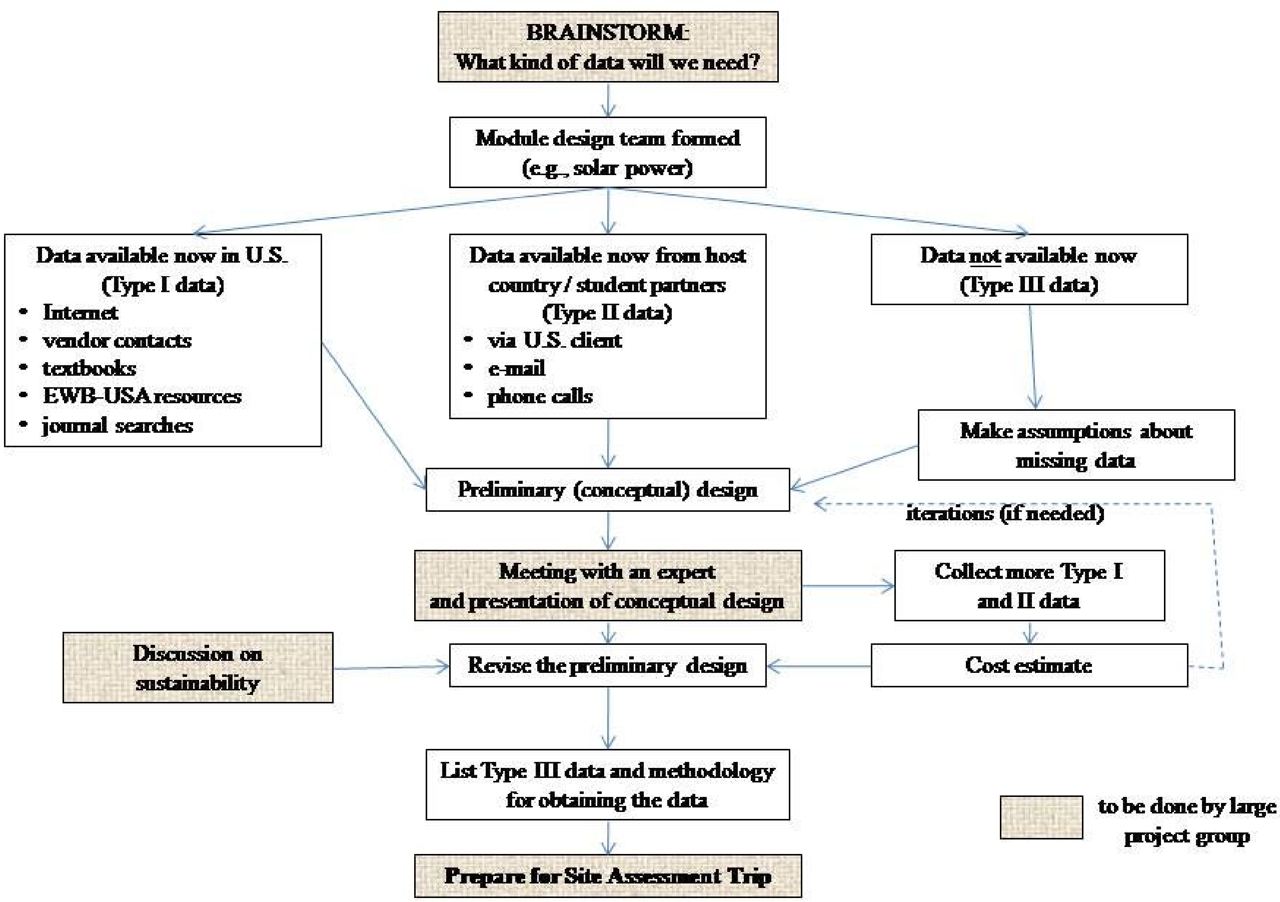
- Engineering encompasses a great <u>diversity</u> of employment types:
    - Consulting – team-working, interpersonal interactions with a client, creative and cost-effective solutions to problems
    - Industry – basic and applied research, problem-solving, design of new processes and components, meeting production and environmental goals
    - Government / regulatory field – protecting the commons, upholding the law and enforcing proper conduct, all within and supported by sound science
    - Academia – research and development, teaching a new generation of engineers, scholarly dissemination of knowledge
- Engineering is an <u>application</u> of mathematics, economics, and a host of physical and natural sciences. In other words, the theory is learned first, but the application for the good of humanity is, in essence, part and parcel of engineering.
- Engineering, in most of its manifestations, involves a <u>client</u>. The profession, therefore, requires a number of "people skills" – communicating effectively, working on a team, understanding a client's needs and positions, understanding the social setting of an engineering problem.

The value of projects using the IPD is that students are introduced further to each of the above characteristics and are able to "practice" engineering as a mentored beginner. The author believes that better decisions about whether or not to continue in engineering education will be made out of the experience of and reflection upon such practice

Methodology for International Project Development (IPD) Design

The IPD design methodology described in this paper is a series of steps that flow sequentially (Figure 1). The process includes initial brainstorming by the larger project team, preliminary design by the smaller module design team, a presentation of the initial design to the larger group, a group meeting with an "expert" – a professional from academia, industry, or government who has experience with the module's technical aspects - to get his/her comments on the initial design, revision of the design, design

Figure 1. Module flowchart for International Project Design methodology



review by the larger group on sustainability issues, and a compilation of data gaps to be collected by the student travel team on the site assessment trip. In essence, the process is an iterative three-way dialogue between the larger group (10-15 students), the module design group (2-4 students), and a recognized expert. Ideally, the larger group is multidisciplinary and "vertically integrated", i.e., comprised of students from freshmen to graduate levels. The process encourages "deep learning" as students actively engage in creative conceptualizing, applying the limited knowledge they have to novel situations, teaching each other from general engineering principles and from their own disciplines, and interacting with a mentor and a professional[5]. Each of the major flowchart steps are discussed below.

Initial brainstorming and design foundation. The brainstorming effort is always the first step in beginning a design module. Each EWB-USA project module has been developed in response to a request by the client (NGO) in the host country. Sometimes the request will be very general, e.g., "Help us find appropriate sources to provide clean water to our village." Or it may be more specific, e.g., "Design a solar-powered energy array that will allow us to take our office and emergency radio transmitter equipment off the grid." In any case, there will often be little to no data/information provided with the initial request. Therefore, in the larger group, students first will discuss the project, learn something of the foundations for design (as would be presented in an introductory class relevant to the topic), and begin to list all possible data that might be needed for the request. The foundations for design will be presented by the group facilitator/mentor or an invited guest who teaches a relevant course on the topic. During this initial process, some students will become more enthusiastic than others about this particular aspect and will volunteer to become part of the module design team.

Module design team. A smaller group of student volunteers will form a separate module design team to take on the bulk of the task work – collecting data, forming a conceptual design, and revising the design. Ideally there will be at least one person on the team who is engaged in the most relevant major discipline (e.g., an electrical or mechanical engineering student for a solar power module) and several others who are still in the GEP and are exploring and considering various engineering disciplines. The older student will mentor the others, as he/she will likely have had at least one course that is pertinent to the module design. The group will function as a multidisciplinary team, as each member approaches the design from his/her own perspective and background, and develop a systems approach to designing the module. These students will conduct meetings on their own as a separate team and report back to the larger group when ready.

Types of data. Once data needs have been compiled, the module design team begins the process of collecting data, making note of uncertainties, possible data ranges, sources of data, and data that is best (or only) obtained via a site assessment trip. The data required generally can be classified into the following types:

- Type I data is available now via immediate sources, such as maps, Internet websites, vendor contacts, reference texts, EWB-USA technical manuals, journal searches or class notes.
- Type II data is available now with additional effort from the host country, a student partner, or other NGOs who have done similar work. This data is more difficult to collect because of language and cultural differences, limited communication options, and/or lack of a trusting working relationship among parties, a goal that needs time to flourish.
- Type III data is information that can best or only be collected on a site assessment trip to the host country. Each piece of missing data will be noted by the design module group as the larger group will need to begin planning for data collection

needs. For purposes of a conceptual design, the module design group can input missing data with reasonable values either from best engineering judgment or from similar case studies.

Preliminary conceptual design. The first presentation back to the larger group will be the preliminary design for the system. This will simply be presented to the larger group for reporting purposes and initial feedback. In the process of developing this first design, assumptions may be made about missing data, or data gaps. The team may fill in these data gaps by using data from other similar projects (such as EWB-USA projects) that seem reasonable and applicable to this design, making careful note of where such assumptions are made. For example, a module team working on a greywater treatment project may not have actual data for typical domestic use in El Salvador, but may have a range of data from Costa Rica or Guatemala that is reasonable to apply. Thus, the preliminary design may be based on accurate Type I and II data, or it may be based in part on reasonable data that has been collected from other projects. In addition, the team may at this point already have a list of Type III data needs. Because there is no academic driver, it is the project coordinator's responsibility to ensure that the team reports back within a few weeks of beginning action. The initial design is in the form of an electronic presentation (such as Power Point) or a hard copy series of sketches and spreadsheets without a cost estimate.

The expert will be given a copy of this design and/or (ideally) attend the design group's presentation. It is important to note that, to this point, the module design team has developed the design on their own, with no input from the expert chosen for this module. The process of self-learning is critical to this methodology as the students will learn just as much (or more) from their struggles and misapprehensions as they will from the words of an expert. Perhaps more importantly, such a process will help the students formulate the best questions to pose to the expert.

Meeting with an expert. The meeting with an expert does not have to take place in a classroom setting but instead could be in the form of a field trip to a vendor's installation or to an office or a laboratory. The purpose of the meeting is to tie together conceptual loose ends that the students may have regarding their design and to be able to refine the design based on professional "in the field" guidance and experience. The meeting with the expert may lead to the need to collect different and/or more pieces of data. This meeting may also result in a new iteration producing additional design options and, consequently, more than one cost estimate.

Cost estimate and design revision. The design module group refines their preliminary design based upon the expert's recommendations and performs cost estimates on one or more design options. This process will be completed before the larger group meets to discuss sustainability issues.

Sustainability review. Sustainable engineering is a multidisciplinary task and will involve all participants for a thorough review. The questions for consideration will depend upon the type of project, but will include at least the following:

- Does the design employ “appropriate technology”, that is, technology that matches its particular context in terms of cost, scale, complexity, cultural acceptability and level of ownership? [2]
- Is the design able to be constructed using local materials and local skilled labor? Concurrently, will the usage of local materials and/or resources deplete these materials/resources faster than they can be replenished?
- Can the design be maintained and sustained by local personnel with relatively low expense?
- Is the design durable, long-lasting, protected from weather, vandalism, theft?
- What potential human health impacts might result from this project? How have these been reduced or eliminated?
- What impact does the design have on the environment? Has any negative impact been minimized?
- What instrumentation or monitoring equipment will be necessary to evaluate ongoing usefulness of the project? What metrics are important and how often should they be measured?

From this review meeting, it should become clear whether or not the design presented by the module design group meets this sustainability review, or if another design should be selected instead. The design is then refined accordingly.

<u>Listing of Type III data and preparation for site assessment trip</u>. This last step is the all-important one of listing in final form the data and information that needs to be collected by the site assessment team. For each data need there will be a methodology and type of equipment needed as well. The group will assess the feasibility of bringing such equipment into the country and/or determining where to borrow or rent equipment within the country. The assistance of the host country’s NGO is critical in procuring this information.

Initial Application and Work on the First Design Module

The request for assistance from EWB-USA came from Chencho Arras, the founder of the Foundation for Self-Sufficiency in Central America, a non-profit group that works closely with the people of the Bajo Lempa region of El Salvador. Based on information given by the Foundation, a new project application form was completed and sent to EWB-USA for project approval. The new project application was reviewed by a national technical advisory committee (TAC) of engineers that investigated the feasibility of the project, as well as the legitimacy and longevity of the requesting NGO, in this case, La Coordinadora. La Coordinadora (LC) is a peasant-run cooperative of eighty-six El Salvadoran villages in the Bajo Lempa region that is seeking to better the lives of its people by providing clean water, owning and managing organic farms and a turtle conservation hatchery, and by long-term planning for rural (eco-) tourism. Once the project was approved by the TAC, the chapter could begin referring to the project as an official EWB-USA project.

Student participation was open to anyone from the student chapter at our university who wished to become involved. Membership on the team is purely voluntary and no course credit is given. The EWB El Salvador project team includes students from Civil, Mechanical, Electrical, Industrial, Chemical, Environmental, and Biomedical Engineering, as well as students in the General Engineering Program (freshmen), Architecture, and Construction Science Management. A Ph.D. graduate student (who is also a Professional Engineer) is acting as the project coordinator, mentor and facilitator of the group meetings. Once this student completes his involvement with the project upon graduation, the chapter will seek another graduate student or upper-level undergraduate student to fill this leadership position. Even though only a subset of the students will travel to the host country, all of the students on the project team have a sense of being involved with the site assessment planning and are invested in the project from the point of view of their chosen discipline and their desire to participate in a worthwhile engineering project. Such an informal structure described here allows a student to stay involved for as long as he/she likes and, like other programs, enables long-term projects[6].

The projects requested by LC have been separated into four modules for the EWB-USA project team:

- solar energy – solar photovoltaic panels for providing backup power to office computers and equipment
- wind energy – assessment of wind resources for organic farming irrigation and a water pumping station
- hydraulics – water distribution system from a cooperative water treatment plant to additional villages on the peninsula, and
- sustainable architecture – green building design, utilities, and layout for a rural tourism project.

Each of these technical modules is being approached in the same manner using the IPD flowchart. Students sign up to join a module design team based on their degree specialty and/or their interest. We anticipate that one or perhaps two design modules may be completed in one semester, with the large group meeting on a biweekly basis.

In the Fall of 2007, the project team tackled the solar energy module. Four students – two graduate / two undergraduate, two women / two men - formed the solar energy module design team. Two were in electrical engineering, one in chemical engineering and one in environmental engineering. Several iterations of e-mails were needed to try and understand the client's needs regarding the solar power. Through this communication the group alternated between various levels of understanding the client's situation. In addition, the client's (LC) priorities and requirements seemed to shift, and each shift required a new variation on the design. Such an exchange was a useful learning experience as the team gradually came to realize that often a client isn't exactly sure what is needed and/or what is possible.

An initial meeting with the large group introduced the topic to the project team and distributed the only e-mail correspondence that included limited information about the client's desires and knowledge of the current electrical system. Under the planning and direction of the project leader, the group pooled their knowledge about solar power in general, conducted a collaborative learning exercise in designing a solar array, and began brainstorming about data needs and possible sources of data for this project (Table 1).

Table 1. Solar power module – the initial fundamentals and brainstorming session

Activity	Outcome
i. Large group – initial state of general knowledge	What are the components of a solar power unit? What data is needed for an initial design?
ii. Divide into smaller groups – an exercise in calculating size of a solar array	Three teams of students worked separately to determine the size of a solar array needed to power a load of particular voltage and amperage [7]
iii. Large group – brainstorming about data needs	Type I data needs: What is the percentage of days that are sunny enough to utilize solar power? Are there any non-profit solar groups in the area or that would be interested in this project? What is a good cost estimate of all the materials needed for the solar power? How long does it take to recharge the batteries? Type II data needs: What components will comprise the load to be powered by the solar array? What is the average number and length of outages? How much time is there between outages? What time of day do most outages occur? What is the pitch of the roof on the office buildings? Type III data needs: How does the client intend to utilize the solar power system? What kind of roof system do the offices have? Can it support a set of solar panels? How will these be mounted? How can the panels best be secured against theft and vandalism?

Then the small module design group began meeting on its own for a few weeks - collecting data, contacting vendors and completing a conceptual design.

Upon completion of this preliminary design, the design group met with the larger project group in the company of an "expert", an Architecture / Mechanical Engineering professor who teaches a course in green building design that includes solar design considerations and components. In addition to his dual departmental appointment, this professor leads the university's involvement in the U.S. Department of Energy's Solar Decathlon, an annual competition among universities to see who can build the most attractive and energy-efficient total solar home. Among other valuable information, this professor was able to force the students to consider additional parameters, such as the expected life of a battery given its usage schedule and power demand, and to incorporate these parameters into a cost/benefit analysis (Table 2).

Based on the ensuing student comments and visible excitement, the discussion was immensely rewarding for students in both the large group and in the smaller solar design group. The meeting with the expert confirmed some of the methodology and assumptions made by the project team. The solar professor even noted that the reference text the group was using was probably the best available for this application! With the expert's help, the meeting also resulted in a listing of Type III data that would need to be collected by the site assessment team for this module (Table 2 includes some representative examples).

Discussion

Whether working in the developed or developing world, sustainable design demands that engineers consider the impact that their technology makes on the current generation as well as on future generations. Problem-solving and project-based learning using EWB-USA projects provide a context in which to explore the integration between social responsibility, human development, and appropriate technology[2],[8]. Furthermore, though engineering students are well aware of the importance of sustainability, there are numerous knowledge gaps regarding the core components of a sustainable design[9]. Research has shown that active learning has many benefits, including positive changes in student self-perception[10], increased self-confidence[11], and increased retention of qualified engineering students[11],[12]. In addition, active experimentation is an important part of the learning process[13], whether that learning is the physics of fluid flow or sustainability. Thus, knowledge that is practiced is knowledge that is more likely understood and retained.

The specific benefits of a real-world, complex problem such as that associated with EWB-USA are manifold:

(1) Engineering students are challenged to think deeply about concepts that fall outside of their chosen discipline, but nonetheless have applications within the engineering field. For example, payback period and cost/benefit analysis are tools used in many engineering disciplines. Fluid flowrate and pressure are civil engineering parameters that have direct correlations in electrical engineering.

(2) Like other group projects, learning in IPD projects takes place across the learning cycle with an emphasis on the preferred learning styles of concrete experience and active experimentation[13]. Students are teaching each other, and, although as individuals they may not have acquired much experience, as a group they can pool together an enormous cache of useful information.

(3) The difference between a scientist and an engineer is that the latter will inevitably be working with a client. This kind of project introduces the student to working with and on behalf of a client, with "all the ambiguities, cultural contexts, and negotiations" that come with such[14].

(4) Students who have not yet decided on a specific engineering discipline will be forced to think across the spectrum of disciplines, better informing this all-important choice.

(5) Students will begin to see the values of engineering fundamentals courses while understanding the diversity of career options and experiencing the humanitarian benefits of engineering.

Table 2. Solar power module – the meeting with an expert and resulting compilation of Type III data needs.

<table>
<tr><th>Activity</th><th>Outcome</th></tr>
<tr><td>i. Large group – meeting with the “expert” (professor in Architecture and Mechanical Engineering)</td><td>

Work towards obtaining a 2 or 3 year payback period for the initial investment. However, in the case of this client, the lost time from power interruptions is what is being saved, and it is hard to put a value on this.
Regarding electric load estimation, determine first if there will be a high peak demand time and, if so, what the peak load will be. For a peak load, consider a second source, such as a diesel generator, wind or the electric grid. Solar can provide a base load at a smaller level. In general, you can use 80% solar power, 20% second source
Regarding using solar as direct or alternating current, the more efficient form of solar electricity is in direct current as there is a great loss of efficiency in using an inverter. So it is best, in general, to encourage the client to use appliances / technology that run from direct current. Avoid having to use an inverter if possible, but if you decide to use one, pick one large one for the whole system rather than individual inverters.
For battery and solar array design –

Size the load; then:

design for voltage, and current gets calculated, or
design for current, and voltage gets calculated.

Decide how many days you need to store power for.
Level of discharge will affect the battery life. For example, if you let the batteries run down, their lifetime gets shortened.

Insolation gives the maximum amount of power the sun can deliver. El Salvador is at about 13°N latitude, so the panel should be set facing the south at a 13 degree angle with the horizon. This will maximize the sun’s potential.
</td></tr>
<tr><td>ii. Large group - determination of Type III data needs</td><td>

Is there wiring for AC power currently installed in the offices? (If so, we should consider using AC and an inverter.)
Which of the offices connected completely to the grid? Does the client want to be off the grid completely for some loads?
What kind of roof system do the offices have? Can it support a set of solar panels? How will these be mounted?
How frequent are the power outages and for how long (duration)?
Are the assumptions made about total loads correct? (e.g., number of computers, radio transmitters, lighting, etc.)
</td></tr>
</table>

Further work with this project could come in many forms. There should be a more intentional approach to integrating the components of the GEP into the project design, especially those components in the first two core engineering courses.

Secondly, learning objectives could be created by the students themselves after being introduced to the project. Such involvement gives greater ownership to the students while giving them a chance to voice real learning questions that they have[12]. Then, once the learning goals are in place, consideration should be given to how these are measured and assessed. The need for a metrics of success in project-based learning is a field ripe for growth in educational research[12]. Current project evaluations are too often dependent upon vignettes and individual student comments upon project completion[12],[15],[16] and more quantifiable, objective measures are needed.

Finally, how do we know that this type of learning increases retention and persistence in the engineering curriculum? Student surveys conducted at this university have thus far focused on students leaving engineering rather than students staying. A finely-focused survey given to participants both before involvement and after involvement with the project is suggested as a research tool of real value.

Conclusion

Many institutions offer design courses (such as "capstone") to students as upper-level undergraduates. However, the excitement of being part of a real engineering project that includes requirements for sustainability, a cost estimate, and a real world application, and that will (usually) be built or implemented is one that bears repeating outside the classroom setting. The multidisciplinary IPD adventure is one that gives the student an actual engineering experience while engaging his/her passion for the social good.

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