2007: COMMUNITY PROJECTS FOR CAPSTONE DESIGN: CASE STUDY

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Community Projects for Capstone Design: Case Study

Abstract

Finding appropriate and challenging projects for Senior Capstone Design can be difficult. Our experience shows that student teams benefit greatly from working with "real world' projects. Projects that have open-ended design problems, coupled with the real constraints faced by the private sector create an ideal environment for completing the student's undergraduate education. Often industrial projects have limited timeframes and the partnership is faced with proprietary information issues. Therefore, we have identified several community interest projects. Most of these projects focus on environmental issues, with particular emphasis on environmental issues and stormwater management.

Projects are solicited from faculty and other professionals who are actively engaged with community activities. Projects are matched with student teams of appropriate background and interests. Each design team has an academic advisor from the Biological Systems Engineering department and a second advisor from the community involved with the problem. These individuals provide advice and coaching to the team, but they are not expected to be the only technical authority or provide design concepts.

The objective of this paper is to show several cases from community projects that have been completed successfully for the capstone experience. These projects include designs to improve water quality and stormwater management in a residential community; design of a raingarden for homeowners; design of stormwater systems for municipal facilities; design of a waste system to decrease the nutrients in an existing international waste treatment facility; waste management from a public fishery and development of an environmental friendly biomass-to-ethanol plant. Student teams collected information on the design requirements including local/state regulations, economic constraints, as well as other site-specific constraints. The project solutions and recommendations were presented to the community and alternative implementation plans were described.

This paper will discuss the design process and the response of the community to the proposed designs. The advantages and disadvantages of these community projects will be compared and contrasted. The benefits from student learning and community education will be discussed.

Introduction

Undergraduate students in engineering face a future in which they will need more than just a solid technical background. In setting the goals for any system they engage to design, practicing engineers are expected to interact effectively with people of widely varying social and educational backgrounds. They will interact with many different technical backgrounds to achieve the desired goals. To meet these needs, engineering education has seen a significant increase in the emphasis on experiential education and on the "professional and social skills," that engineering students will need when they enter the workplace.

Among the most dramatic statements about the importance of these skills are the set of desired educational outcomes that form the heart of the engineering accreditation criteria, once called

“Engineering Criteria 2000,” that went into effect in the United States in 2000[1]. In addition to knowledge of engineering, mathematics, and science, and experience in engineering problem solving and system design, these criteria call for students to be able to function on multidisciplinary teams and to communicate effectively. They also call for students to understand a wide range of issues, including the importance of professional and ethical responsibility and the societal and global impacts of engineering solutions.

One effective response to the reforms is a curriculum that engages students in “real-world” experiences[2-8]. The design of these experiences is crucial; they must offer students a compelling context for engineering design, a multi-disciplinary team experience, sufficient time to learn and practice professional skills, personalized mentoring, and exciting technical challenges. The combination of these five characteristics ensures that students will immerse themselves in the engineering experience, thus learning the desired skills and addressing the desired issues as they perform their tasks.

Industrial projects have been a successful strategy to address “real-world” experiences but industrial projects have limited timeframes and the partnerships often face proprietary information issues. Community organizations have a growing need for engineering expertise and solutions. Community service, educational and state agencies face a future in which they must rely to a great extent upon technology for the delivery, coordination, accounting, and improvement of the services they provide. They often possess neither the expertise to use nor the budget to design and acquire a technological solution that is suited for their mission. Thus, they need help from persons with a competent technical background.

Methodology

The methodology of introducing “real-world” engineering design to undergraduate students involves the creation of a mutually beneficial university/industry/community partnership. The university and its students benefit from having industry/community involved in the definition, guidance and evaluation of the student projects, while industry/community benefits by having the material and intellectual resources of the university involved with relevant problems. This approach contributes to the student’s understanding of the way problems are approached and solved in practice. Engineering curricula that use “real-world” problems are better able to train students to compete in the changing environment of the world. These students can use these experiences and concepts of the marketplace, continuous quality improvement and understand non-engineering constraints of design used by practicing engineers.

The community partner has the task of defining the design problem in a format and time frame to fit an undergraduate team and academic year. The problem should be of inportance and financial interest to the community. The community is obliged to monitor the project to keep it on track and mentor the design team to provide the community perspective that lies beyond the traditional university laboratory and classroom experience. The university provides the traditional mentoring and academic evaluation but also provides the necessary resources to make the project a success for students and the project partners. The use of any specialized equipment or space necessary for the project is negotiated at the initiation of the project with the understanding that the prime role of the design team is the education of the students. Again, the community takes responsibility for any extra-ordinary expenses and requests for facilities not normally available to students for project work.

Project Selection

The projects are limited only by the existing expertise of the departmental faculty and the time frame available for completion. Some of the case projects were initiated by faculty involved in interest groups, interest groups contacting the instructor, or a student soliciting ideas from their peers and the community. After the project definition, projects are matched with student teams of appropriate background and interests. Each design team has an academic advisor from the Biological Systems Engineering department and a second advisor from the community providing the problem. The advisors provide coaching to the team, but they are not expected to be the only technical authority or provide design concepts.

The community partner must realize that there is no guarantee of a solution to a rigidly defined problem and that the time that students can devote to a project is a crucial factor. Thus, the problem definition is a crucial concern in selecting projects for both the community and students and, for example, a project that may impact the immediate economic health of the community would be rejected. The more closely the objectives and realizable goals are defined, the higher the probability of success.

Project Cases

The section below demonstrates several projects from community projects, their deliverables, and the community response.

"Developing Raingarden Design Criteria for Residential Homes"

Raingardens are stormwater management devices that can reduce runoff by infiltrating the water, and replenishes the groundwater supply. As opposed to curb and gutter or detention ponds, which are two other stormwater management practices, raingardens are aesthetically pleasing

and can be more cost effective. Raingardens are applicable in residential areas, which was a main design criterion for the project. Raingardens are used for recycling water to residential water systems for the homeowners' use. Additionally, raingardens can decrease the degradation of streams, aquatic habitats, and reduce peak-flow rates during storm events by allowing the water to infiltrate, and eliminate sediment and excessive nutrients from reaching the water body.

A user-friendly software program was developed to assist in the design and implementation of residential raingardens. The inputs to this software program are the county, lot size, impervious lot area, and hydrologic soil group. The output results in acceptable raingarden dimensions that vary based on the ratio of soil mix depth and gravel depth, and available depth in the homeowner's yard. Cost of the raingarden implementation and materials is included in the analysis. A final design was developed for a test site, and the site design was re-evaluated and reassessed in an interactive process to improve and modify the design, which then was used to improve the computer program.

The design process for raingardens, functional software program, user manual, and an information brochure for homeowners to encourage the use of raingardens were developed. In order to complete the design, the team met with raingarden specialists at Virginia Tech Horticulture department to address vegetative requirements. The resulting product included a raingarden design for a specific site in northern Virginia. The acceptable raingarden dimensions were about 37 m^2 and the estimated cost ranged between \$3,000 and \$6,000. The main components of a raingarden cost are the amount of soil fill mix, gravel, mulch, plants, pipes and labor expenses. Additional cost variables are based on the surface area of the raingarden, and the ratio of the soil mixture to gravel layer below the surface of the raingarden.

The team not only addressed the design and educational aspects of the project; they considered the audience who would benefit. It was not only necessary to develop a functional design and program, but also to present this program in a format that would be appropriate for use by the general public. The community partners (WWSI) were pleased and felt that the team had a good understanding of stormwater management.

"Design of a Residential Stormwater Management System for the Boardwalk Community at Smith Mountain Lake"

The problems associated with stormwater management include nutrient loading from fertilizers and sedimentation and erosion from high peak flows. Many conventional stormwater management systems direct stormwater to a single site for collection. A new approach to stormwater management is known as Low Impact Development (LID). The "Boardwalk" is a lakefront development on Smith Mountain Lake. The community desired to retrofit the current stormwater management system with a newer and environmentally friendly LID stormwater management system(s).

The "Boardwalk" is faced with many of the problems associated with conventional stormwater management. The current system directs runoff as quickly as possible off the development and into the lake. This causes high peak flow runoff rates, sediment, and nutrient loading problems that are and will continue to degrade the water quality of the lake.

The residents of the "Boardwalk" community were also interested in the development of a water quality monitoring plan to determine the effectiveness of the LID practices implemented in their community. The project consisted of instructions on how, when, where and what to sample as well as recommendations for equipment and procedures to be used and an estimated cost. This plan is vital to monitoring success since the personnel doing the work had very little experience.

Another important part of LID is community involvement. This included suggestions for a community outreach plan to make people aware of the issues associated with stormwater management. The report gave suggested events and example brochures the community can use for educating residents.

Design included the specifications for two bioretention basins and water quality swales and a cost analysis for each of these practices. The first site was located at a dead end where the road loops. Inside the loop is a grassed area with one mature tree. The drainage area was 0.13 ha of which 0.01 ha was covered by impervious asphalt and 0.10 ha was covered with grass. The ponding area was calculated to be 33 m^2 with a depth of 15 cm. The design requires 25 kL of planting soil. This structure was estimated at $840 for materials.

The second site was chosen because it consists of a large common area. This area was lined by stormwater drainage swales which exit through a single culvert. The drainage area was 0.5 ha, of which 0.05 ha was impervious. The ponding area of the bioretention basin was 48 m^2 with a ponding depth of 15 cm. A mulch layer was necessary to cover the planting soil surface. The mulch layer consisted of shredded hardwood chips. There shall be four trees and eight shrubs for a total of twelve plants for this site. The structure was estimated at $1,249 for the materials.

Implementation of pervious pavement within the project area was recommended. These areas were broken into footpath and pathways. The cost for these pervious pavements were $38,610 for the footpath and $915,508 for the roadways.

The project team presented these finding to the Smith Mountain Lake Homeowners and the activities were reported in several newspapers. The area developers were engaged and will be considering these concepts in future development.

"Reducing Urban Stormwater Impacts within the Stroubles Creek Watershed"

Increasing urbanization has led to progressive degradation of water quality in area streams. Several localities are beginning to turn to retrofitting stormwater management practices to mitigate environmental impacts.

Since much of the Town of Blacksburg and Virginia Tech's campus was constructed without adequate stormwater controls, Stroubles Creek has been listed as "impaired" as a result of excessive sediment, nutrients, and water quantity issues. Currently, stormwater runoff from existing parking lots at local community centers drains directly to a tributary of Stroubles Creek without detention or treatment. A method of treatment is necessary to control the quantity and quality of water leaving these facilities and entering the stream.

As the amount of impervious surface in the townships increases, the volume and velocity of stormwater runoff flow increases. These increases in flow have detrimental impacts on Stroubles Creek, that flows through Blacksburg and Virginia Tech. As a result, a TMDL was developed for Stroubles Creek and town officials are seeking ways to help reduce the volume and velocity of stormwater that enter the current stormwater infrastructure.

The goals of these BMPs are to allow effective and efficient detention and treatment of stormwater and to develop a prototype that can be used for similar implementation projects throughout the town. In order to obtain these goals, the project involves developing a model to simulate the hydrologic processes of a BMP, and designing two effective BMPs to detain and retain stormwater flows from the community facilities. The model will serve as a user-friendly interface to a program that will determine the optimum design parameters for a BMP given the location's allowable space dimensions, the area's soil properties and the type of porous medium needed for construction.

Two BMPs were designed such that the space used for their construction is limited to areas bordering the existing parking lot and constrained by parking areas, slope, utilities, and future expansion. Together, they will intercept all runoff from the 7,300 m^2 Community Center lot and the 1,600 m^2 Aquatic Center lot and allows infiltrate through the porous medium, either infiltrating through the bed to the existing soil or flowing out of the outflow pipe into the existing stormwater system. These methods decrease the total amount of water introduced to the stream and dramatically reduces the velocity of the water entering the stream systems, while also increasing the amount of water entering the original soil as groundwater recharge. Monitoring equipment was recommended to allow analysis of the BMP's effectiveness in reducing stormwater flows. All project deliverables were presented to the Town of Blacksburg and construction is scheduled during the summer of 2007.

"Design of Maturation Pond, Aquaculture, and Wetland for Wastewater Treatment"

Puntacana Resort and Club, located on the southeast coast of the Dominican Republic, requested a preliminary design of a waste stabilization system to decrease the nutrients in their current waste treatment facility. High levels of nutrients from coastal resorts wastewaters are entering the ocean and slowly destroying the coral reefs. Puntacana Resort and Club and the Dominican people rely heavily on tourism and the coral reefs are an essential part of the attraction. Nitrogen levels were identified as the primary concern in these coastal waters and the project objective was to limit the quantity of nitrogen that enters coastal waters.

A modified wastewater treatment system was designed that produces effluent that poses minimal threat to the coastal waters and can be redirected for irrigating lawn and garden areas in the

resort complex. Before this wastewater is released as effluent, it will pass through three systems. The current facility has just two facultative ponds. The design calls for an addition pond facility to be constructed. Water will flow from the existing facultative ponds to a maturation pond where the water is retained for 2.3 days while suspended solids settle and algae consumes the excessive nitrogen. The existing fecal coliform bacteria counts are estimated to drop to 50 cfu /100 mL, a level that is safe for aquaculture production (tilapia).

The effluent from the maturation pond supplies an aquaculture facility where tilapia consume the algae. Tilapia is harvested and consumed by the resort guests or sold on local market. The fish market value was estimated at $17,170 annual return. Finally, water is filtered through a constructed wetland for final nutrient and pollutant removal before irrigating local gardens and golf courses. This system has an estimated removal of 5.51 mg/L of nitrogen, which is approximately 86.6% more than the existing wastewater facility. The initial cost was estimated at $150,820 and the cost to maintain the 3-unit system at a productive and effective level was estimated at $21,520 per year. The constructed wetland serves as an educational attraction to resort guests interested in learning about the ecological benefits of wetlands and water quality issues in the Dominican Republic.

"Paint Bank Fish Hatchery (PBFH) Raceway Residue Management"

Increased concern for the health of our natural ecosystems, especially aquatic habitats within the Chesapeake Bay watershed, has led to higher levels of involvement by the state government in

protecting water quality in our rivers and streams. Degrading water quality decreases natural fish populations, which affects the livelihoods of those who fish for a living as well as a hobby. The effluent from PBFH is released into Potts Creek, which eventually flows into the Chesapeake Bay. Recently, the Virginia Department of Environmental Quality (DEQ) imposed stronger regulations, which restricted the PBFH from releasing the settled solids from the hatchery raceways into the stream. Their current method for waste collection and disposal is time consuming and expensive.

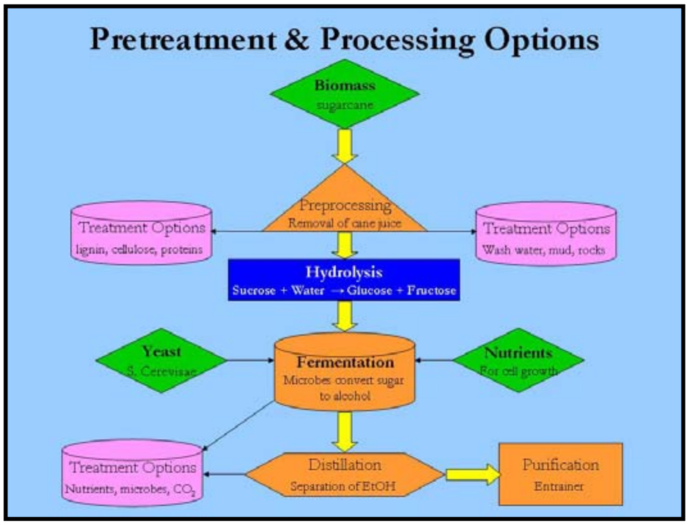
Paint Bank Fish Hatchery produces approximately 64,400 kg of brook, brown, and rainbow trout annually, for stocking in natural waters. The hatchery produces approximately 37,800 L of sludge per year that is currently taken off-site five times throughout the year by a septic hauler. PBFH management seeks alternatives to their current waste collection and disposal issues that allow effluent within the DEQ effluent limitations.

Alternatives in waste collection and disposal methods were investigated. Examples of improved waste collection methods employ microscreens, and biological filters such as Aquamats®. Examples of improved waste disposal alternatives are the use of anaerobic digesters, composting units, land application, and septic fields. Environmental and safety regulations were researched and compiled regarding water quality, nutrient levels, and waste handling sanitation issues for hatchery employees.

The project determined that composting is the most viable waste treatment process for PBFH, based on its relative efficiency or waste degradation, low cost of operation, and low environmental impact. The group developed parameters needed to operate a composter, such as amount of land and bulking agent required, as well as potential uses for the final composted product.

"Design of a Sustainable Biomass-to-Ethanol Plant for Farmers in Fiji"

As a developing country, Fiji needs a green, independent, and economic source of aviation fuel. A design of a biomass to ethanol process plant could provide Fiji a sustainable production of 1.89 million L/yr for transportation fuel. The design of a biomass-to-ethanol plant in a developing country requires extensive management due to technological limitations and process suitability for the region.



The four major by-products of ethanol production from sugarcane are: bagasse, filter mud, carbon dioxide and stillage. The 10,000 t/yr of bagasse produced from sucrose extraction can generate 75 kW electricity in addition to satisfying the energy needs of the plant. The plant is expected to produce 1,560 t/yr of filter mud, which will be returned to sugarcane plantations for application as fertilizer. Fermentation, or the microbial conversion of sugars to alcohol, produces equal moles of carbon dioxide as ethanol, for a total of over 1,400 t/yr CO_2. A CO_2 recovery system is recommended to enable sale of this by-product for beverage carbonation, fire extinguishers, or dry ice in Fiji.

To meet production capacity, the plant has been designed to operate 24 h/day and 300 days/yr, with the remaining 65 days of non-production to allow for regular cleaning, maintenance, and unscheduled repairs. The production process is designed for minimal water use and will recycle up to 95% process water to lessen resource consumption and reduce treatment capacity, without sacrifice of efficiency and quality.

The wastewater treatment system utilizes an anaerobic lagoon, two facultative stabilization ponds and two maturation ponds to treat the stillage and wash water resulting from the ethanol production process. Design of the treatment system is based on the five day biochemical oxygen demand (BOD_5) concentration of the plant effluent and a design flow rate of 90,000 L/d. The total land area required for the pond system is 0.624 ha (1.5 acres). The BOD_5 of the plant effluent will be reduced from 12 g/L to 20 mg/L before discharge to the nearest water body or routed to sugarcane fields for irrigation. This treatment system requires minimal technical expertise to operate, and minor, infrequent maintenance.

Lessons Learned

Taken as a whole, the community projects were a success and we believe that the projects convey the "real-world" view of how engineering design is accomplished in our communities and their experiences are far better than the traditional capstone experiences offered by many. As these community projects show successful outcomes, the future design projects should be self-sustaining.

These undergraduate design experiences are not without fault and have room for improvement. The common sense improvements include starting the project at the earliest possible date. This entails having a defined project from the community as soon as student teams are available to work on the project. Efforts to define projects and to recruit new community projects now are beginning in the summer with the hope that teams will start early in the fall semester. Some students have expressed interest in beginning the project in the summer. As more communities subscribe to the design project concept, we hope that this phase will become less labor intensive for the advisors and facilitators.

Probably the most important contribution to having a successful project is the degree to which the communities work directly with the student teams. A direct association between the degree of success of the projects and the support that the student team received from the community partner is strongly linked. The projects need a strong focus and the potential for completion. The academic course requires more formal and frequent progress reports since the teams often delayed work due to the pressures of other classes and extra-curricular activities. Requiring the teams to document when a task will be performed and assessing their progress is very valuable to the completion of the project.

Conclusion

The differences between engineering design teams in universities and "engineering teams for hire" are numerous. Students are novices both in their domain knowledge and in their knowledge of the design process. Students often work in unstructured teams of peers, even if roles such as team leader have been assigned. They often judge their success by the grade they earn or by the prototypes they produce. The client (whether it is a professor, community or interest group) rarely plans to use the team's design as presented. Rather, the goal is for the students to learn about the design process and to master new domain knowledge. On the other hand, professionals are expected to be domain experts, assigned to projects based on their skills, producing a product that the company can profit from or a community can benefit from. Learning, and the accumulation of shared knowledge, is rarely an explicit goal for "engineers for hire." However, these community projects have teachable moments that are shared by all those involved.

The community project design experience appears to be an excellent model to introduce students to “real-world” design process. The mentoring, problem definition and evaluation made possible by community partners is an element that was not previously experienced by the undergraduate.

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