Teaching Sustainable Design Using Engineering Economics

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Abstract:

The objective for a junior level course entitled "Introduction to Environmental Engineering" is to introduce the student to environmental engineering fundamentals and to examine the principles of an environmental ethic that will lead to sustainability for humans and the ecological systems that support us. An essential part of the class is a design project in which the students design a "Center for Sustainable Education". The facility must utilize sustainable technologies for power, heating, cooling, and water supply. The students must demonstrate financial feasibility of their project through the development of a business plan that provides a detailed analysis of construction costs, operating expenses and revenues. The cost of renewable resources must be compared to conventional resources. The students are given an initial "startup grant" of 1.5 million dollars and are expected to leverage this money through innovative strategies to cover the cost of design and construction.

This paper addresses the evolution of this course and includes its shortcomings as well as successes. The course has been taught using active learning principles for the last four years. Technologies such as photovoltaic and passive solar system design are taught using just-in-time methods. The role of engineering economics and its impact on sustainable design in the class is reviewed. Finally, the course is contrasted with more traditional Introduction to Environmental Engineering courses.

Background

Introduction to Environmental Engineering is a three credit hour junior level class that has undergone continual change. The class is a time delayed image of changes within the profession of environmental engineering. The current catalog description of the course is as follows':

> "Introduction to the engineering aspects of environmental systems to include such topics as water quality management, air pollution and control, solid and hazardous waste management, environmental impact assessment, and governmental regulation".

Over the past eight years the class has been taught once a year. During this time five different individuals have taught the course. The author has taught the class for the last four years. Although all instructors were engineers with terminal degrees, each instructor has had a very different background and little effort was has been made to coordinate the instructional content of the class from year to year. A variety of texts were used and the approach to the class varied with each individual. The emphasis of the class changed from year to year. For two years the emphasis was in environmental health and safety, for another year the emphasis was wastewater treatment, and for the fourth year the emphasis was air pollution. The class did not have a theme or fixed content. This created an advising problem because students could not be informed with any certainty regarding course content or how the course would mesh with the two required undergraduate environmental classes.

The author first taught the course in Fall of 1994. He obtained syllabi from the previous instructors and prepared a syllabus that can best be described as hybrid mix of water resources, solid waste and environmental law. The syllabus was designed to address material not covered in the two required undergraduate environmental classes. This approach was similar to that of the previous instructors and was not the product of deep reflection regarding the role of the course in the curriculum. Grading for the class was conventional with three hour exams, weekly quizzes, daily home work, one research paper and a final exam. At the conclusion of the semester the author felt that he had done an adequate job but that the class was not unified. Rather, the class was an assemblage of pieces that never really quite tit together to make a complete picture of the puzzle. Still, student evaluations for the class were well above the departmental average. Unfortunately, students do not usually know what course content should be for an elective; therefore, student evaluations were not a good source of information for content modifications.

Course Ideology

A unifying theme was needed for this class that would enable students to pull the individual elements that comprise the course into the larger vision of what it is that environmental engineers do for society. Most environmentalists believe that environmental problems are the result of human kind’s interaction with the world around us; an interaction that, in part, has produced many negative outcomes. Examples are abundant: respiratory problems due to air pollution caused by transportation and energy production; pathogenic disease risk from water sheds polluted by agricultural and industrial activity; and cancer risks created by the disinfectants we use to protect ourselves from the pathogens that human activity introduced into the water shed in the first place. The path of environmental problems is circular and always returns to its source - human activity that is not in harmony with the natural world that supports us.

Transportation is a necessary part of commerce. So is the use of our natural resources for agricultural production. Engineers directly support both of these and many other development activities. Is engineering fundamentally at odds with the natural world on which we depend? Will society and its engineers continue to design, build and develop until we push ourselves to the point where we can no longer support the infrastructure we have constructed? Certainly, there should be some unifying principle that can be taught in an introductory environmental engineering class that will some how convince students that it is possible for engineers to be part of the solution and not contribute to our own destruction. Is human life and civilization sustainable or will we extinguish ourselves?

Contained in these questions is today’s environmental buzzword - sustainability. The term used in a politically correct context is “sustainable development”. Sustainable development is something of an oxymoron and students are the first to seize on this contradiction in terminology. Politicians equate development with jobs and a prosperous economy. What could be better than an ideology that allows for sustained development while simultaneously protecting the environment?

An ideology was needed with more depth and content than the politically popular phrase "sustainable development". A philosophy or ideology was needed that encompassed the principles of science and engineering. The author stumbled onto such an ideology in activities that UTEP was involved in as a member of Historically Black Colleges and Minority Institutions (HBCU/MI) consortium. The HBCU/MI is composed of 17 member institutions and was initially funded by the U.S. Department of Energy. The HBCU/MI consortium joined with Second Nature out of Boston, MA, in an effort to infuse the principles of sustainability at the university level. This enabled Second Nature to reach all 17 institutions at once by successfully obtaining an endorsement of the Second Nature agenda at HBCU/MI steering committee and presidental committee meetings with member institutions. The author was UTEP's HBCU/MI steering committee representative and attended four Second Nature workshops as a result of this involvement.

TNS

Second Nature adopted The Natural Step (TNS) ideology[2]. TNS originated in Sweden and was championed by Karl Henrik-Robert. The fundamental concept is that the biophysical world is the basis for life and that students must understand the nature of the biophysical world, how it works and why it is sustainable. Fundamental to this thinking is that development is only sustainable if system integrity is maintained.[3] The President's Council on Sustainable Development adopted the following definition of sustainable development "..to meet the needs of the present without compromising the ability of future generations to meet their own needs."[4] The vision statement of the President's Council is stated as "Our vision is of a life-sustaining Earth. We are committed to the achievement of a dignified, peaceful, and equitable existence. A sustainable United States will have a growing economy that provides equitable opportunities for satisfying livelihoods and a safe healthy, high quality life for current and future generations. Our nation will protect its environment, its natural resource base, and the functions and viability of natural systems on which all life depends. "[5]

Out of this fundamental vision specific precepts are set forth:
1. Human population size is maintained within carrying capacity of natural systems;
2. Physical and natural resources are used no faster than they can be replenished;
3. The assimilative capacity of natural systems is not exceeded;
4. Global life support systems are maintained; and
5. Efficiency and equity characterize the use of all natural resources.

Out of the precepts listed above several principles involving economic activity and their relationship to ecological systems can be stated that have direct impact on an introductory course in environmental engineering. These have been stated as "economic activity must be subject to true cost accounting which will entail new approaches such as exploring economic value as a function of energy flows, ecological processes preserved and maintained, or resiliency of systems to collapse" and "should emphasize efficiency and adaptability, provide work that is meaningful, valued and biophysically compatible for every individual."' These are lofty statements and are not always easily put into practice. The principal of sustainability does, however, serve as an ideological foundation on which the course content for Introduction to Environmental Engineering can be built.

Design Project

The Accreditation Board for Engineering and Technology (ABET) strongly encourages integration of design throughout the undergraduate curriculum. ABET's goals along with positive experiences the author has had with design projects in other courses led to the integration of a sustainable design project into the course. The students must design a "Center for Sustainable Education". The facility must utilize sustainable technologies for power, heating, cooling, and water supply and wastewater treatment. The proposed facility is to be located adjacent to a mountainous wilderness park 10 miles from El Paso. The project must incorporate renewable energy and water sources and utilize locally available materials for construction. The facility design must include housing, conference facilities, and recreational opportunities. The design project connects directly to the course ideology of sustainability while providing a very real design experience.

The structure of the course has evolved over the last four years. Student input has been used to modify the organization of the design project each year. During the second year the course was taught, design teams of four members each were randomly selected. In the third year project team members were selected by the author to represent a cross section of abilities and skill levels needed to work on the project. This worked better than the random team selection process but students complained of the heavy work load and amount of time required to produce a high quality design project. During an open discussion students recommended that the entire class be involved in the same design project so that the work load could be divided and a higher quality product with more detail be produced. Based on these recommendations, the design team for the the fourth year consisted of multiple specialty teams. Each team selects or is assigned a design area based on team capabilities and interest as shown in Figure 1. One team, carefully selected by the instructor, is responsible for project management and economic analysis. The three other teams are water systems design, structural design and site layout, and energy systems. The team structure is similar to that found in an engineering consulting firm thereby enabling the finished project to be much more detailed and rich.

Economic Analysis

The students must demonstrate financial feasibility of their project through the development of a business plan that provides a detailed analysis of construction costs, operating expenses and revenues. The cost of renewable resources must be compared to conventional resources. The students are given an initial "startup grant" of 1.5 million dollars and are expected to leverage this money through innovative strategies to cover the cost of design and construction. Professional and technical staff salaries must be included in the operational expenses. Debt payback and operational costs must be covered by workshop and conference fees. The design team is free to create their own schedule of workshops and target audiences.

During the early stages of the project the teams must submit a joint **concept proposal** that is agreed upon by all teams. The concept proposal is reviewed by the instructor. Class time is allocated for a joint discussion of the instructor's suggestions and possible alternatives. Using class time is much more effective than written comments alone. The concept proposal also specifically defines each teams project responsibilities. Coordination methods between the teams are worked out at this time Approximately one month later the **technical design report** is due. At this stage numerous problems arise. Teams that are behind schedule do not have adequate detail in their technical analysis and they are unable to provide the management team with their portion of the detailed cost analysis. Since this is a critical time, arranging individual one hour meetings outside of class with each team to go over their technical design is very productive. This also makes the management team's job much easier. The **final report** is submitted either the week before or after the **team presentation.** This allows the team members to focus on one thing at a time and minimizes crisis management.

The economic analysis is prepared by the project management team and is based on input from the other task teams. The project management team has the difficult job of controlling costs. The tendency is for the design teams to want to come in over budget for their part of the project. "Buy in" by the team members has been very strong and this leads to intense discussions and difficult decisions on what can be included and what cannot. Figure 2 is an example of one "what if' scenario for facility utilization. In this case the team was using present worth analyses of various annual cash flow scenarios to determine project sensitivity to client utilization. The economic analysis included sensitivity evaluation for both the number of participants and the number of seminars held during the year. The management team also did a sensitivity analysis for capital cost versus facility plan area. This was powerful tool for keeping the size of the facility under control by determining which activities were essential to project goals.

Economic analysis was a powerful tool for this class. The students came to appreciate the importance of controlling costs when profitability is tied directly to the ability to bring in income, capital cost and operational expenditures. Sanders in another introduction to environmental engineering class found that the use of a design project and active learning methodology was also very helpful.[6] Cost comparisons between sustainable technologies and standard technologies were relatively easy to conduct because of the remote site location. The electric and water utilities were contacted and asked for the cost to provide service to the site. Electrical power was close by so the connection charge was low. The watt hour cost was high for the State of Texas. However, the annualized cost for grid power was much lower than on-site photovoltaic and/or wind energy. On the other hand, the annual cost for on-site water supply was much lower despite the high cost of desalting the saline groundwater. This occurred because of the very high cost of bringing city water to the remote site.

Conclusions

The development of an environmental ideology for the course provided the instructor and the students with a framework that was helpful to both. It also provided a very human as well as intellectual connection to the subject and the students' work as future engineers. The use of economic analysis was a powerful tool that maximized team collaboration and kept the project down to earth. The pun is intented.

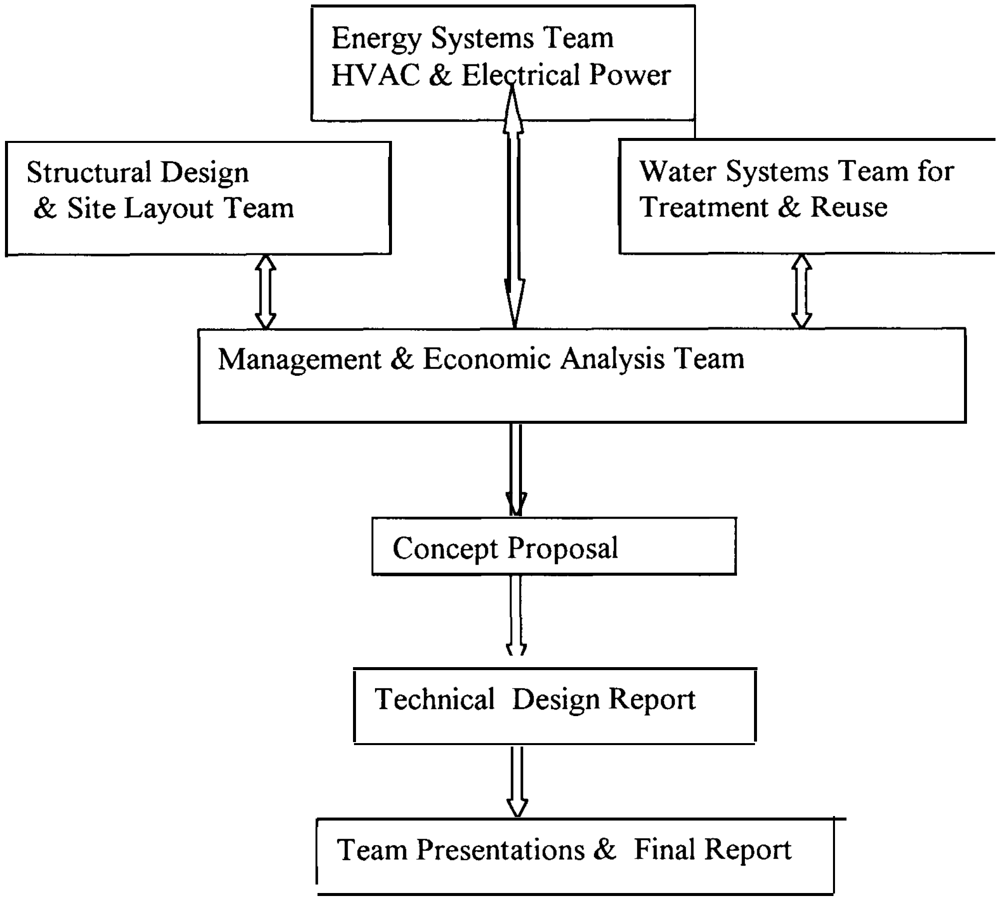
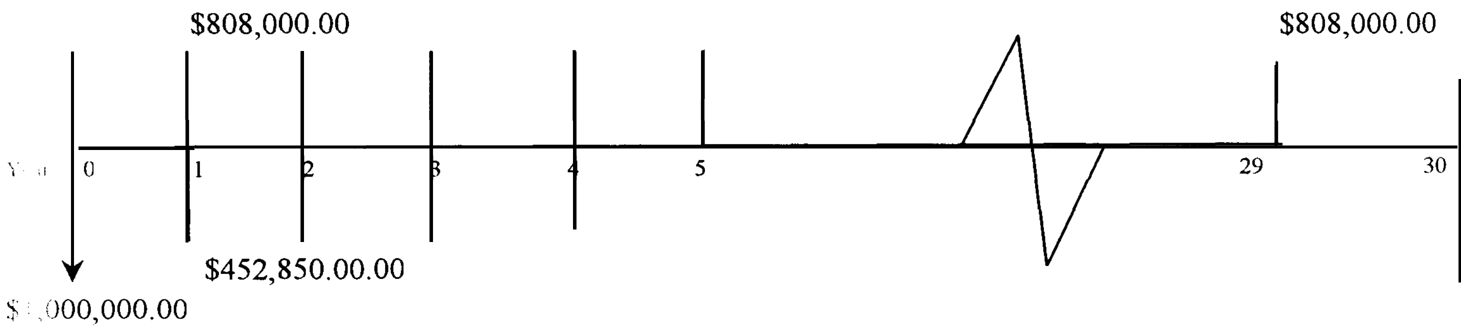


Figure 1. Design project organizational chart for Introduction to Environmental Engineering



Initial Cost of facility is estimated at $2.5 million.
$1.5 million of initial cost will be financed at 8% interest rate to be paid in 4 years at $452,850.00 per year
Annual Cost (including salaries) is estimated at $200,000.00 per year.
Annual Revenue from center is estimated at $1,008,000.00 per year running at 100% capacity for 48 weeks. The weekly rate is estimated at $700.00 per person.
Annual Revenue - Annual Cost = $808,00.00.00
Minimum Attractive Rate of Return 6%
Present Worth = -$1,000,000.00 - $452,850.00(P/A,6%,4) + $1,008,000.00(P/A,6%,30)
Present Worth =11,305,747.87

Figure 2. Present Worth Analysis from Student Design Project Cost Analysis

1. University of Texas at El Paso, “Undergraduate Studies Catalog 1996-1998”, El Paso, Texas.

2. Hawken, Paul; “Taking the Natural Step”, *In Context*, No. 41, Summer 1995.

3. Workshop on the Principles of Sustainability in Higher Education, held under the auspices of The President’s Council on Sustainable Development - Public Linkage, Dialogue and Education Task Force, February 24-27, 1995, Essex, Massachusetts.

4. World Commission on Environment and Development (The Bruntland Commission), Our *Common Future,* Oxford University Press, 1987.

5. The President’s Council on Sustainable Development, *Sustainable America - A New Consensus,* ISBN 0- 16-048529-0, February 1996.

6. Sanders, Dee Ann; “Renewal of a Flagging Environmental Engineering Program: Start at the Beginning,” *Journal of Engineering Education,* July 1995.