Integrating Engineering Design Heuristics into a First Year Engineering Course to Enhance Problem Solving and Team Building Skills

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Abstract - This paper presents an approach to integrating a module on design into a first year engineering course with goals to facilitate students' systematic methodology to design while building team skills. At the beginning of their academic careers students are usually competent in basic science and math, but have limitations in integrating this knowledge with solving a practical problem. This limitation has been addressed by creating student teams to design and build a trebuchet. Each team is required to design, develop and produce a working trebuchet using a problem-solving heuristic composed of five steps: define the problem, generate solutions, decide on a course of action, implement the solution and evaluate the solution. Several interactive classroom exercises were used to introduce problem solving techniques such as brainstorming and Osborne's checklist. Next, they were introduced to decision analysis tools to assess solutions based on a list of performance objectives and design constraints. After presenting their findings to the class in oral presentations, each team's design was evaluated in a trebuchet throwing contest and winners awarded by faculty. The success of the curriculum changes will ultimately be assessed through critical analysis of the students' design capabilities at graduation.

Index Terms – engineering education, design, problem solving.

INTRODUCTION

Recently there has been a lot of discussion about the limitations of engineering education. We, as educators, are adept at traditional lecturing and assigning closed-ended problems. However, recent findings note that students need to learn by doing, and that creative design skills can be sharpened if exercised regularly. According to the Boyer Commission on undergraduate education [1] *"faculty should be alert to the need to help students discover how to frame meaningful questions thoughtfully rather than merely seeking answers because computers can provide them. The thought processes to identify problems should be emphasized from the first year, along with the readiness to use technology to fullest advantage."*

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Although design courses are mandatory requirements for all accredited engineering schools in the United States, in many cases these courses have become a technical exercise at the senior level since it is believed that lower[1] level students do not possess the technical knowledge to complete a design. As a result, current engineering educational strategies are not as productive as they could be.

Several recent papers have proposed techniques for integrating design throughout a civil engineering curriculum. For example, Kartam [5] illustrated several pragmatic approaches such as introducing design competitions within classes, using a multimedia approach, and integrating research into the classroom. Kaiser and Troxell [4] illustrate the benefits of integrating competition into an undergraduate design course to foster innovative thinking. They also found that the learning experience is dramatically improved by providing a unique hands-on learning environment.

In the United States, the Accreditation Board for Engineering and Technology {ABET}, Inc., is responsible for the specialized accreditation of educational programs in applied science, computing, engineering, and technology. The ABET learning outcomes for the Civil Engineering program at the University of Alabama in Huntsville (UAH) are:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Student Learning Outcomes are similar in most engineering school in the United States. They are assessed throughout the students' academic careers and at graduation.

Although Outcome (c) is an obvious design requirement, numerous other outcomes (notably a, b, e, and k) are also directly related to the implementation of design.

In 2000 the UAH undergraduate curriculum committee proposed several changes in the curriculum to facilitate the design experience for the undergraduate students to meet the new ABET criteria. The major addition was a required course for the incoming freshman (CE 101 – Prelude to Civil Engineering) that allowed the new students to meet the civil engineering faculty, as well as other engineering students in a design oriented cou[2]rse. Other changes included a design course in each of the four major civil engineering areas (environmental, geotechnical, structural, and transportation) in the third year of the curriculum in addition to the overall senior capstone design course. This paper will present the objective, structure and results of the new first-year course.

COURSE OBJECTIVE AND CONTENT

CE 101, Prelude to Civil Engineering, is a primer in the practice of civil engineering and engineering design concepts. The course consists of lectures and seminars by faculty and professionals depicting the different branches of civil engineering and student exercises that require the planning and design of a team project. Students are required to write a short design proposal and present their results. A primary objective is to provide the novice Civil Engineering student with hands-on application of the principles of design and an opportunity for creativity.

This course was first offered in 2001 with a class of 18 students. One professor is assigned responsibility for the overall course and other faculty members act as team mentors.

The project assigned to the students motivates students to use all levels of Bloom's Taxonomy for cognitive domain: integrating (1) knowledge to (2) comprehension through (3) application, (4) analysis: (5) synthesis, and (6) evaluation. In a semester of fifteen weeks, six classes directly relate to the trebuchet design project. Table I illustrates a planned progression of typical lecture topics.

TABLE I
CLASS DESIGN PROJECT SCHEDULE

Week	Topic
Week 9	Lecture on problem solving techniques (#1. Define the problem)
Week 10	Brain storming session on building a trebuchet (human-powered catapult) in teams (#2. Generate solutions)
Week 11	Formulate theoretical design according to constraints Submit a Gantt Chart with your team's plan (#3 Decide on a course of action)
Week 12	Introduction to MS Excel software for data analysis and power point for presentations
Week 13	Design Build Projects – CE labs (#4. Implement the solution)
Week 14	Test the trebuchets and adjust the throwing arm and counterweight position. (#5 Evaluate the solution)
Week 15	Competition: Give oral presentation with computer-generated visual aids and test trebuchets in parking lot

Team Project Module

The first step in the design module is a presentation on design heuristics providing the students the necessary tools of creativity & knowledge to develop solutions. Through the use of interactive classroom exercises they are introduced to the problem solving heuristic approach that was developed by Fogler and LeBlanc [3].

1. Problem Definition
2. Generate Solutions
3. Decide on a Course of Action
4. Implement the Solution
5. Evaluate the Solution

At the conclusion of this lecture, the students are divided into teams. The student teams are given the following design challenge: design and build a citrus hurling trebuchet with your CE 101 team within cost and size constraints using only three soda cans as counterweights. The team with the longest consistent throwing range will be hailed as the CE design champion for the year.

Trebuchets are ancient weapons that work like first class levers [2]. Most first-year students have not completed a college dynamics course, but have knowledge of basic physics. The challenge is to act as an effective team unit to investigate and address such issues as equilibrium, friction, and force. Only a basic background on trebuchets is provided. Otherwise each team must design, develop and implement research options for the frame, counterweight (three soda cans), beam, sling and guide chute. Many websites offer design examples and guidance, hence, the rigor of the theoretical design is not overly complicated for the students.

Teambuilding skills are required to successfully complete this assignment. To aid in the teambuilding process, the first interactive task during week ten (10) is a "team scavenger hunt" that facilitates communication among the members. The students are delegated to teams of four to five and then handed a form asking questions such as:

- Find someone in your team who played a sport in high school
- Find someone in your team who lives in a town smaller than 10,000 inhabitants
- Find someone in your team who has a movie or event ticket on them
- Find someone in your team who has an exotic pet (not a dog or cat)
- Find someone in your team who comes from a large family (over 3 kids)

A student in each team acts as the facilitator, another as secretary and a third as the presenter. This task starts dialogue and allows members to become acquainted in a short time. Then each team must come to the front of the class and introduce their team and present the results of the scavenger hunt. Usually some of the answers are slightly twisted and laughter is common. This process prompts after-the-class discussions within and across teams.

On week twelve (12), each team must give an oral presentation that incorporates the team objectives and approach to solving the design problem, so one lecture is concerned with making an interesting presentation. This lecture incorporates MS PowerPoint and excel software basics and advice on slide content, formatting, animation, and themes. The benefits of this lecture extend throughout their college coursework for the presentations they will be required to make in most of their subsequent civil engineering classes.

The final class period is dedicated to the competition itself and is held outdoors. The teams line up their machines on the starting line and each is given three attempts with the counterweights (soda cans) and a fresh orange supplied by the instructor to avoid any tampering. Figure 1 shows two of the teams with their designs at the starting line. All the CE faculty members help with the event and the department chair awards the winners' certificates and T-shirts.

FIGURE 1
THE 2007 TREBUCHET CHALLENGE AT UAH.

RESULTS

The course has been offered for six years since its inception in 2001. The students rate the class using a standard "instructor evaluation form" at the end of each semester. This course has consistently received high marks (over 90% agreement) for teaching methods and quality of instruction. The students are encouraged to make comments on the back of the form. Here are some of our students' comments:
"Team design project coupled with design approach is an excellent approach."
"I was able to meet other CE students through the CE 101 design project and now have a support group for other classes."
"I enjoyed the design/build project"

A survey is given to every senior student prior to graduation with several questions relevant to CE 101 for two years. The questions were:

1. CE 101 was helpful in introducing "what civil engineers do".
2. CE 101 was beneficial in helping me to network with other CE students
3. The team design/build project in CE 101 provided me with a good primer in hands-on design experience

The student may respond with the following assessments: strongly agree, agree, neutral, disagree, strongly disagree. Table II shows the percentages of each response.

TABLE II
SENIOR SURVEY RESULTS

Question	Responses				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	76%	20%	4%	0	0
2	61%	30%	9%	0	0
3	38%	50%	9%	3%	0

The sample size of the senior survey was small due, n = 32. However the majority of students agreed that the course was beneficial for both networking within school and also a good first design experience. A full analysis of the course's impact on retention will be performed the upcoming year.

CONCLUSIONS

A design problem and competition has proven to be a valuable and constructive tool for undergraduate students. It gives them the opportunity to practice their design/build skills while using innovation to propel their projectile. The success of the curriculum changes will ultimately be assessed through critical analysis of the students' design capabilities at graduation.

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