Using a Hands-On, Project-Based Approach to Introduce Civil Engineering to Freshmen

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Abstract

At the University of North Carolina at Charlotte, the second semester freshman course "Introduction to Engineering" is discipline specific. This course gives students an introduction to the particular discipline (Civil, Electrical and Computer, Mechanical) through a project-based experience. In Civil Engineering, this course has involved the conceptual design of a Civil structure loosely tied to a FORTRAN programming course unit. Lately, we have completely revamped this course. While computer programming instruction remains, we now teach MATLAB, software that is currently being used in several other courses that are part of the Civil Engineering curriculum. In addition, we now teach MATLAB during a balsa wood bridge design competition, in which groups of students compete to build the truss-style bridge having the highest benefit (a function of strength) and lowest cost. Structural, cost, and profit analyses are done using MATLAB scripts that students write as homework assignments through the semester. In course units on Dimensional and Engineering Analyses, students learn how to compute the tensile and compressive member strengths, and the load on each member. These units are combined with MATLAB instruction that enables the students to write a script that analyzes candidate bridge designs. Two recent developments have assisted the course redesign. First, we have developed an automated grading system to administer distribution, grading, and submission of MATLAB homeworks. Second, custom publishing is used to create a textbook that includes information on each course topic. During the last week of the semester, student groups present their designs in an oral presentation, and each bridge is destructively tested for strength. Cost and benefit analyses are performed immediately during the contest, and a winner is declared on the last day of class. So far student feedback on the course redesign is positive.

Introduction

Recent developments in the freshman engineering curricula at the University of North Carolina at Charlotte mirror those of many other universities. In the past five years, a common core curriculum for all engineers has been adopted for the first semester "Introduction to Engineering Course." In this course, all prospective engineers are introduced to the design process and to the various engineering professions through a group project that requires interdisciplinary design. The second semester course, which originally had a component common to all majors, has recently been returned completely to the separate engineering departments (Civil, Mechanical, Electrical and Computer). Mechanical Engineering now uses the second semester freshman engineering course to teach three-dimensional solids modeling with Pro ENGINEER, while Electrical and Computer Engineering offers their students an opportunity to work on a group-based microelectronics fabrication project.

Of the three departments, the curriculum for the Civil Engineering department has been the most fluid. Although the course has typically combined some sort of design experience with instruction in computer programming, the details of how this was implemented varied significantly from year to year. Several different conceptual design experiences were attempted, but in each case the instructors struggled with the challenge of giving the students an interesting, comprehensive, and at least semi-realistic design experience that was appropriate for those with no background in Civil Engineering. Added to this challenge was the burden of working in instruction on FORTRAN, the computer programming language most familiar to the faculty. While student ratings of this course were not terrible, thanks to the dedication of the instructors involved, it was generally agreed by the faculty that a more engaging and instructive introduction to Civil Engineering was desirable.

A revised curriculum for the course was introduced for the Spring 2002 semester, at the same time complete control of the course was returned to the individual departments. Like before, the class includes programming instruction, but the class now teaches MATLAB[6] programming, as do other engineering programs.[3,5,7] The course also retains the design experience from before, but it is now provided through a group-based design competition. In our case, groups of one to three students compete against one another to produce the most "profitable" truss-style balsa wood bridge. During the semester the students develop MATLAB programs that they can use to estimate the costs and benefits of various candidate bridge designs. Other course units on Dimensional and Engineering Analysis provide instruction on the strength and loads expected on individual bridge members. The course culminates with oral presentations describing each group's design and destructive testing of the bridges. Costs, benefits, and profits of each group's bridge are calculated during the contest so that the winning entry can be announced immediately after the last bridge is broken. Grades for the group project are based not only on the bridge's profit, but also on the quality of the oral presentation and on the accuracy of the strength estimate produced by the group's MATLAB program.

The essential elements of this second semester freshman engineering course, such as the "hands-on" activities, the group-based design project, and the competition, have been recently incorporated into several other freshman engineering courses. DeJong et al.[4] have developed an Introduction to Engineering course at Baylor University that also includes a truss-style balsa wood bridge contest. In their class, however, students use commercial software packages to perform the structural analysis. Wilk et al.[11] describe their freshman engineering course, which is organized around the course theme of intelligent transportation systems. This course also includes hands-on experiences, as do others,[3] and an element of competition to improve student interest and engagement. The inclusion of a design project, performed by groups of students is now an element of many freshman engineering courses.[2,4,8,10]

The following section describes the motivation behind the redesign of the course. This is followed by a description of the various elements of the course and how these elements are implemented in the course. The article concludes with discussion of student and instructor assessments of the course so far.

Course Development

Development of the course started by listing the desirable course attributes that we were trying to achieve. Some of the desirable attributes include:

- the content should be appropriate for second semester freshman Civil Engineers;
- the course should model the design methodology performed by practicing Civil Engineers;
- the technical content should provide the students at least a limited level of conceptual understanding of the strength of various bridge trusses;
- the course should provide an opportunity for students to learn the basics concepts of procedure-based computer programming;
- the technical content in the course should be transferable to later Civil Engineering coursework;
- the course should provide sufficient opportunity to use MATLAB so that the student's would be able to use MATLAB in subsequent Science and Engineering coursework;
- the course should motivate student's to learn MATLAB programming;
- the course should provide opportunities for hands-on experiences;
- the course should demonstrate that excellence in Civil Engineering work requires technical expertise, insight, and creativity;
- the course should make students aware that shoddy construction can ruin excellent engineering design;
- administration of a class of 100 students by one instructor and two TA's should not require an unreasonably large amount of work; and
- students should find the course interesting, intellectually challenging, and eventually rewarding and fun.

After consideration of these attributes and after discussion with the faculty who had either previously taught the course, or teach sophomore level Civil Engineering courses, the basic concept of a balsa bridge contest emerged. To make the technical content suitable for freshmen, the bridges would all need to be truss-style, as the structural analysis of other bridge types would require technical analysis too advanced for freshmen. Even so, the structural analysis of a truss would require teaching the students elements of static equilibrium that are usually taught during the sophomore level Statics course. It would also be necessary to teach the students how to calculate the tensile and compressive strength of an individual balsa wood member. From these considerations came two additional desirable attributes of the course:

- students should gain a conceptual appreciation of how vertical loads on a truss are carried by individual truss members; and
- students should learn how to determine, with just hand calculations, the strength of a triangular balsa wood truss given information on member lengths and cross-sectional dimensions.

Course Description

To meet the course objectives as outlined in the set of desirable attributes listed above, the technical course content is organized into three main units (Figure 1). Lectures focused on two of these units (MATLAB, Engineering Analysis). The balsa bridge construction unit is performed as a hands-on experience by the students as they build, test, and rebuild their bridges. To create a competitive entry in the bridge competition, students must rely on knowledge from all three of the course units (Figure 1).

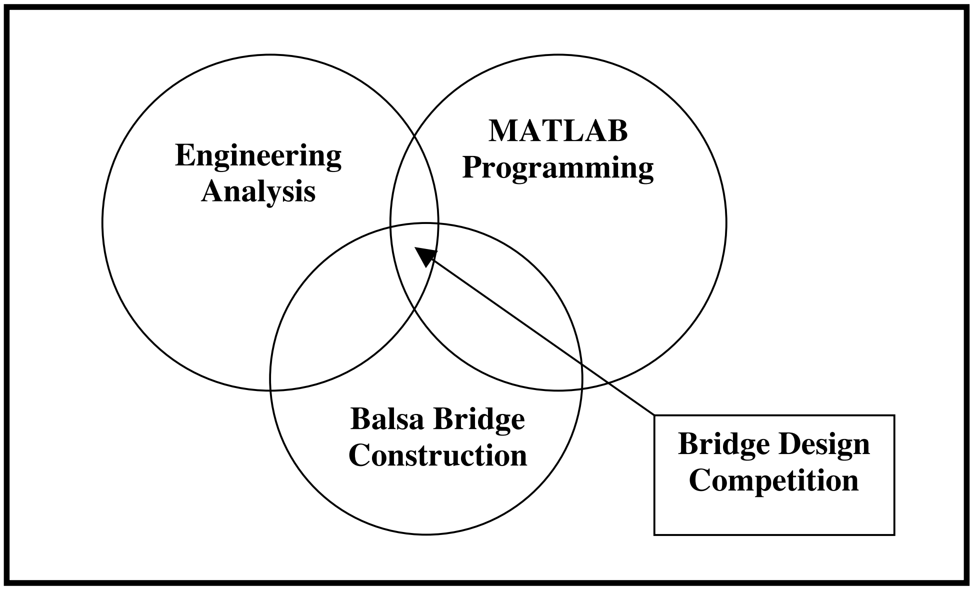


Figure 1. Relationship of Course Technical Elements

The lecture portion of the course can be divided into lecture topics that concern specific information within either the Engineering Analysis or MATLAB programming units (Table 1). A similar number of lectures are devoted to each of these topics. Two lectures are used to develop the equations giving the tensile and compressive strengths of an individual balsa wood member. These equations are developed as part of a hands-on experience. First the principal of dimensional consistency of engineering equations is explained and examples are given. In the next lecture, students work in groups and are given balsa wood pieces of various lengths and cross-sectional dimensions. They perform qualitative compressive strength tests at their desk by compressing the various pieces. Using this information, and with some assistance by the instructor as to which parameters are in the tensile and compressive strength equations, these equations are developed using the principal of dimensional consistency.

Course Administration

The course is administered using the typical combination of homeworks, quizzes, in-class exams, a final, and the design contest. Homeworks are assigned on roughly a weekly basis,

Table 1. Course Topics for Freshman Engineering Course

Course Topic	50-minute class periods
Class introduction, the assignment system, the balsa bridge contest	1
Introduction to MATLAB, creating scalars, vectors, matrices, how to write, check, and submit a homework script, doing arithmetic w/ MATLAB, special matrices, math and trig functions	2
MATLAB data types, solving calculus problems using the symbolic data type, equation solving, finding differentials and integrals	2
Bridge basics, types of bridges, components of a truss bridge, types of truss bridges, how a structure carries a load	2
Dimensional consistency, computing the strength of a truss member in tension and compression	2
Analyze a truss, working with scalars and vectors, vector operations, vector components, finding magnitude and direction, forces	4
Using MATLAB function "jbtruss" to analyze a truss	1
Creating a structural model, free body diagrams, reactions, static equilibrium, calculating reactions, calculating internal member forces, stress and strain, truss analysis, static determinancy of a truss, safety factors, strength of a truss,	9
Problem solving w/ MATLAB, script input and output (input, disp)	1
Simple x-y plots w/ MATLAB, log plots, multiple plots, changing plot appearance	2
Statement-level control, simple if statements, relational and logical operators, if – else, elseif, nested if statements, looping, for loops, colon notation, while loops, example scripts	5
Balsa wood bridge contest	3

excepting weeks having a quiz (there are four of these) or an in-class exam (there is one of these). Overall there are eight homework assignments. The quizzes occupy one-half of a 50-minute class period, while the exam occupies the entire class period. Weekly help sessions are offered in one of the computer labs within the College of Engineering.

Because of the relatively large number of homework assignments (8) and the large class size (80 – 100 students), a special automated grading system was developed to handle administration of homeworks.[1] Distribution of homeworks, student homework submission, and return of graded assignments are handled electronically using the homework system using web-based interactive forms. A particularly nice feature of the system is that students are able to grade their assignments on their own before submission. This is particularly important for the MATLAB assignments, where one syntax error will make the entire program unusable. A special MATLAB script (check_script) is available to any student running MATLAB on one of the College of Engineering's UNIX or PC computers. Students can also download the needed scripts to their own computer if they wish. Using this script, and the other scripts that are used with it, the student provides his or her student ID, the assignment number, the file location, and the file name. The student's MATLAB script is then run, and the results compared to a database of correct answers. The assignment grade is then calculated, and the grading results are presented to the student.

Four of the assignments require the student to perform a structural analysis of their candidate bridge design. The final two assignments require the student to calculate estimated bridge benefits and bridge costs. The estimated bridge benefit is calculated as a function of estimated bridge strength (Figure 2), which is determined from the structural analysis of the bridge. The function used to calculate benefits is made available to the students either as a MATLAB function or as an EXCEL spreadsheet. A second MATLAB function is available to calculate bridge costs, which are related to several characteristics of the bridge design such as its weight, the number of nodes, and the number and size of member types (Figure 3).

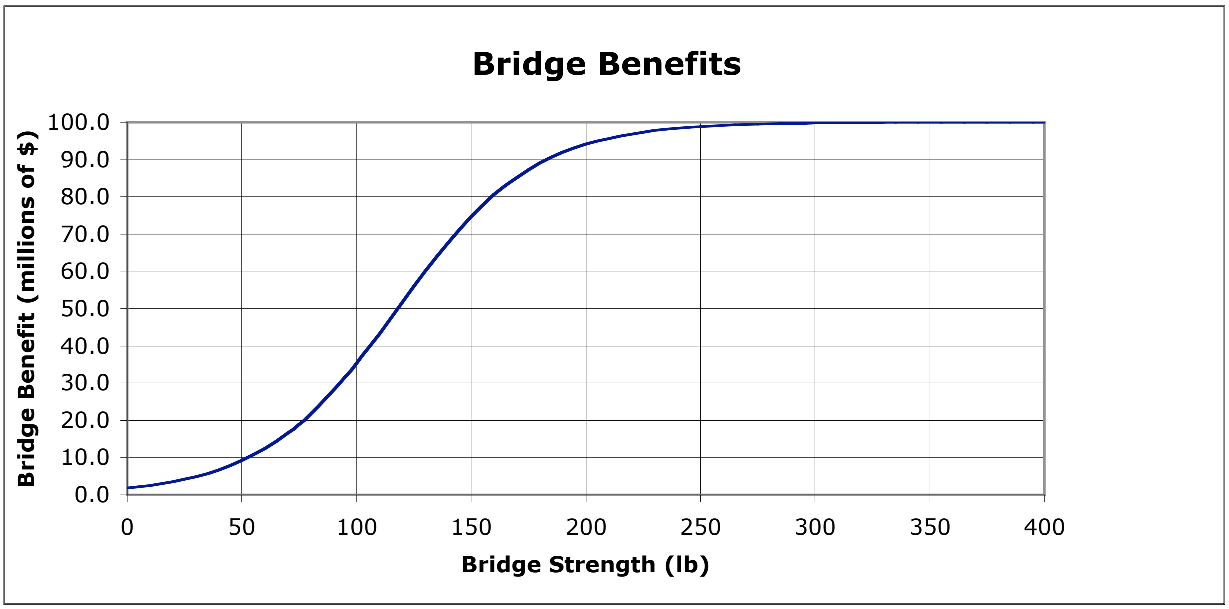
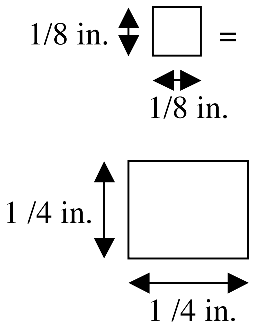


Figure 2. Function used to determine bridge benefits as a function of bridge strength

A very specific set of rules on other aspects of the bridge design (height, width, length, construction materials, etc.)[15] provided to the students on the class web site.[9] This web site also contains links that allows students to pick up new homework assignments, previously graded assignments, as well as previous tests, the class syllabus, and other class information.

The actual bridge competition is held during the last week of the class. Each group hands in an entry form that gives all the numbers needed to determine the cost of their bridge. The group then gives a short oral presentation describing their entry. The actual bridge is then placed in the load frame and destructively tested for strength. An Excel spreadsheet is used to calculate bridge costs, benefits, and profits. This necessary information is input into a laptop computer, and the results displayed with a data projector (Table 2) to all the students. Once the final bridge is broken, the final contest rankings are set. This information is later added to the class web page.

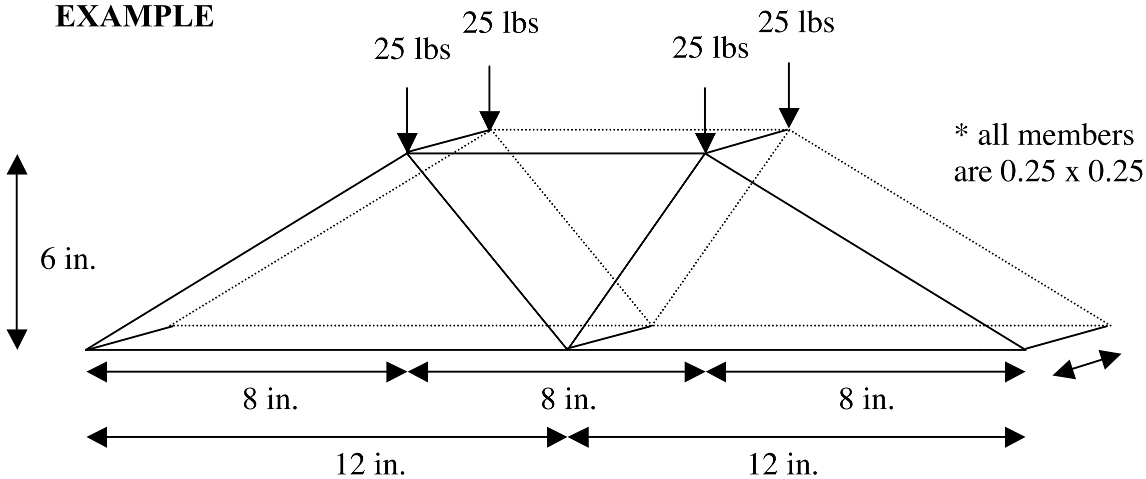


1/8 in. x 1/8 in. = $5,000/linear inch

1 /4 in. x 1 /4 in. = $30,000/linear inch

Member Types = $100,000/member type
Decking, Pavement, Other Fixed Costs = $5E6
Engineering Fee = $500,000
Nodes = $100,000/Node
Weight Costs = $150,000/gram of model weight

EXAMPLE



From Matlab -> Sum of member length's = 66.42 inches/truss
Number of Nodes = 5 nodes/truss
Model Weight = 60 grams
Minimum Safety Factor (SF) = 0.95

COST:

2 (trusses) * [66.42 (inches/truss) * $30,000/inch] =	$3,985,200
2 (trusses) * [5 (nodes/truss) * $100,000/node] =	$1,000,000
1 member type * $100,000/member type =	$100,000
Weight Dependent Costs = $150,000 /gram * 60 grams =	$9,000,000
Engineering Fee + Decking, Pavement, Other Fixed =	$5,500,000
TOTAL COST =	**$19,585,200**

Figure 3. Example Cost Calculation for Bridge Entry

Table 2. Sample Bridge Contest Results

Group	Length Small (in.)	Length Large (in.)	# nodes	# mem types	Weight (g)	Cost (million $)	Estimated Strength (lb)	Acutal Strength (lb)	Benefit (million $)	Profit (million $)	Profit Rank
L	0	125.0	52	1	79.2	26.431	238	323.0	99.901	73.47	1
E	0	223.0	28	2	97.0	29.740	200	225.0	97.359	67.62	5
M	0	257.0	32	1	99.5	31.435	180	363.6	99.975	68.54	2
H	70.7	166.0	20	2	50.0	20.534	90	178.0	88.314	67.78	4
U	0	283.0	14	2	103.5	31.112	430	251.4	98.899	67.79	3
J	0	236.9	24	1	96.4	29.566	180	211.6	95.913	66.35	8
S	0	250.0	32	1	98.4	31.061	404	238.2	98.292	67.23	6
I	0	283.6	24	2	103.6	32.143	100	268.2	99.372	67.23	7
AA	**0**	**419.2**	**10**	**2**	124.4	37.936	**571**	**600.0**	100.000	62.06	11
Z	0	151.7	24	2	83.3	25.147	200	175.5	87.416	62.27	10
L	79.5	59.5	20	4	46.5	17.058	225	162.0	81.503	64.45	9
J	0	390.7	22	1	96.0	33.921	181.7	197.0	93.482	59.56	14
B	32	406.0	16	3	125.0	38.490	200	310.0	99.846	61.36	12
G	0	366.0	52	2	116.2	39.314	275	234.8	98.088	58.77	15
D	0	556.2	18	4	122.2	42.716	250	273.0	99.465	56.75	17

Course Assessment

The course as it has been described here has been taught twice, in the Spring 2002 and the Fall 2002 semesters. Information from the standard end-of-semester student evaluations are available for both semesters, but the survey data are not very helpful in assessing the relative effectiveness of this particular course format. Previous to the change in course format, students generally rated this course below the Department and College averages on questions dealing with satisfaction with the course and the student's assessment of how much they learned during the course. Students now rate the course slightly above Department and College averages on these measures, although these differences are not statistically significant and are confounded by slight wording changes in the survey questions. Based on observations of students both in and out of class, students seem to particularly like the bridge design contest aspect of the course. In both semesters, several groups of students have taken the initiative to build and destructively test several candidate bridge designs well in advance of the actual contest. There has seemed to be a consistently high level of interest in the last few weeks of the class on such topics as the advantages and disadvantages of different types of glues and different ways to reinforce bridge joints. Several students in their written comments on course evaluations said that they had fun designing, building, and testing their bridge design. Students were generally quite enthusiastic in class during the final weeks of the semester and during the competition itself.

Student assessments of the other two technical elements of the class, MATLAB programming and Engineering Analysis (Figure 1), have been mixed. Student ratings of the MATLAB programming portion of the course have been somewhat negative. Several students have commented that they didn't think they had learned enough to be considered MATLAB programmers. These students seem to consider this portion of the course to be overly challenging. Some students have complained that those with previous programming experience have an unfair advantage. Students have also commented through written comments on the course evaluations that more lecture material needs to be devoted to MATLAB instruction. In response to these comments, we are now in the process of adjusting slightly the lectures so that more lecture time is spent in the MATLAB portion of the course. Students do seem to be motivated to learn the MATLAB portion of the course, judging from their attendance and behavior at optional MATLAB help sessions. It is somewhat difficult to discern, however, whether their motivation to learn MATLAB has been increased by coupling the instruction to the bridge contest. Nonetheless, this coupling has definitely helped the course from the instructor's point of view, as it has made it much easier to show students how the programming skills can be applied to solve real problems. The coupling has also made it easier to formulate programming assignments that test the students' knowledge without seeming to be simply "busy" work. The Engineering Analysis section of the class has generally received less criticism than the MATLAB section on the written comments made as part of the end-of-semester evaluations. Students have also seemed to perform better on quizzes and on homework assignments during this part of the course.

Administration of the course so far has been very time consuming. Most of the time has been spent on administration of the MATLAB programming of the course. In particular, creation of homework assignments and setup of the grading system have taken far longer than would traditional assignments. On the other hand, grading has gone much faster than it would by standard methods. Considering the fact that as many as 800 assignments may be graded during a semester, the overall time commitment is probably not unreasonable. In addition, we expect that once the grading systems are more thoroughly debugged grading will be less time consuming than it is currently. In fact, we have seen a downward trend in the time needed to grade assignments each semester. In course evaluations, students rate the course above Department and College averages on questions related to the speed in which graded assignments are returned, and in the fairness of the grading system. This is an impressive achievement, considering the relatively large size of the class and the large number of assignments. Overall class performance has generally been quite good, with only one or two D's or F's each semester. In both semesters, students have done very well on the homework assignments, both in their average grade and also in the number of assignments that they completed. Only a small number of students failed to do all of the assignments.

The overall assessment of the class by students and faculty is positive. Students like the format, and most of the desirable traits of the course are being at least partially achieved. We hope the time required to administer the class will decrease to manageable levels once the grading systems have been used two or three times. It is also hoped that student performance on and student opinion of the MATLAB component of the class will improve in the future as we further refine our instruction.

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