Project Enhanced Learning in Structural Analysis

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Abstract - This paper discusses implementation of the projects into a junior level introductory structural analysis course. The goals of the projects, and the changes made to make room for the projects are also discussed in detail. Assessment and evaluation of the impact of these projects include an evaluation on how the courses and projects address specific department and Accreditation Board for Engineering and Technology learning outcomes. Student perceptions are evaluated immediately at the conclusion of the course and substantially after the conclusion of the course (while in a senior design course). Performance in this senior design course also is used to assess the impact these projects by comparing those with and with out project experience in their structural analysis course. The process of balancing the outcomes for this course with the needs of follow-on courses, and the tradeoffs that are needed to accomplish both could be applied to any junior level engineering course.

Index Terms – Assessment and evaluation, Learning outcomes, Project-based learning, Structural analysis

INTRODUCTION

An introductory structural analysis course has been modified to incorporate design-oriented team projects based on realistic civil-engineering systems. These projects are open ended problems with multiple possible solutions and are designed to emphasize interpretation of numerical results rather than pure numerical computations. Critical thinking and evaluation results in improved learning outcomes.. In addition, the project teams give the students experiences needed to improve ABET and TAMU departmental outcomes, specifically:

- TAMU 1. Ability to apply knowledge of basic mathematics, science, and engineering [ABET a]
- TAMU 2. Ability to function on multi-disciplinary teams [ABET d]
- TAMU 3. Ability to formulate and solve civil\ocean engineering problems [ABET e]
- TAMU 4. Ability to communicate effectively (verbal & written) [ABET g]
- TAMU 5. Ability to use computers to solve civil\ocean engineering problems [ABET k]

These projects require students to: (1) tackle a larger and more realistic civil engineering dynamics problem, (2) use computational tools in solving problems, (3) exercise critical thinking and communication skills. The projects are presented to student teams, acting as consultants on the project (TAMU 2). The projects are more realistic and more complex than standard homework assignments. Computer software applications are used to solve the numerical component of the projects. The content in these courses was modified to include conversion of a physical system (structure and corresponding loads) into the most adequate mathematical model in order to perform the analyses (TAMU 1 and 3). A detailed written report and discussion is part of the submission requirement and counts as a third of the project grade (TAMU 4). Finally, the students are required to use approximate methods to evaluate the results from the computer software package (TAMU 5). This requirement is important in helping students develop the ability to evaluate reasonableness of computer results; to find errors in the model or input; and to choose among alternate solutions.

ORIGINAL COURSE DESCRIPTION

The original course is much like most structural analysis courses. Once esoteric topics such as cables, arches, curved beams, etc. are removed a "typical" syllabus might include:

1. Analysis of determinate beams and frames
   - Determinacy
   - Reactions, Shear, and Moment Diagrams
2. Analysis of Trusses
   - Classification
   - Method of Sections
   - Method of Joints
3. Influence lines for determinate structures.
   - Trusses
   - Beams
   - Vertical loads on frames
   - Moving loads
4. Approximate Indeterminate Analysis.
   - Portal Method.
   - Cantilever Method
   - Moment Diagram from Deflected Shapes
5. Deflections
   - Double Integration.
   - Moment-Area
   - Conjugate Beam
   - Virtual Work
   - Virtual Work for Trusses
   - Virtual Work for Beams

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- Virtual Work for Frames
- Theorems of Maxwell, Betti and Castigliano

6. Indeterminate analysis
   - Superposition
   - Influence lines for Indeterminate Beams, Frames and Trusses
   - Slope-deflection Equation
   - Moment distribution without side sway
   - Moment distribution with side sway
   - Introduction to Matrix Structural Analysis

Of course, other topics (such as column analogy) often were added at the discretion of the instructor. Faced with covering all of these topics, most faculty would resist the insertion of meaningful projects into the course.

COURSE MODIFICATIONS

The authors decided that projects were the best way to approach many of the learning outcomes presented by ABET. Like problem- or project-based learning (PBL) students develop a deeper understanding of the subject area by focusing upon a realistic problem[2,3,4]. Like PBL our goals are to aid students in the acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills. Unlike PBL, where students work in small groups to explore and develop a solution to a "real-world" problem under the guidance of a facilitator/instructor, projects in these courses are used as a supplement to traditional instruction. By requiring students to expand on course material to tackle a bigger problem, we (like PBL) hope to encourage students to take charge of their own learning.

Something significant cannot be added without consideration of what should be deleted. The depth of understanding that can come from a project is well worth the sacrifice of ***some*** superficial learning on selected topics. Typically, several methods for computing deflections, etc are included in junior level analysis courses. These topics are still covered in the courses, and it would be difficult to incorporate the projects into a class that did not include them. However, only one or two methods are now covered, to allow for time to discuss topics and discussions specifically on project topics. For example, significant time has been spent on modeling, loads, and approximate methods. Specific changes in the individual courses are contained in previous papers by the authors[5,6]. Choice of topics to be covered or omitted from a course cannot be made in a vacuum, and should be made in consultation with instructors of parallel and subsequent courses.

The insertion of projects into an existing class is not without peril. Students are used to homework and quizzes; they do not learn the same things from projects; and often do not feel that projects prepared them *"for the exam"*. The most frustrating comments come from those who *"LEARNED THE MOST FROM THE PROJECTS"*, while complaining that the projects took to much time, hurt their grades as they could not spend their time in other course activities. In short, our goals of student learning don't match well with their goal of maximizing grades.

Part of the student discomfort can be addressed by explicitly telling them that the projects are geared towards developing and assessing a different set of skills than homework and exams. The projects are graded based on their analytical content as well as the evaluation and presentation of the results, and this fact must be emphasized to the students. Additionally, the project grade must be a significant percent of the final course grade in order for the students to take the experience seriously and gain the benefits from the experience. In our experience, the projects must be a minimum of 10% of the final course grade to achieve this.

PROJECT OBJECTIVES & SELECTION

These projects have several objectives: (1) to allow students to tackle a larger and more realistic civil engineering problem, (2) expose students to computational tools used in solving civil engineering problems, (3) evaluate critical thinking and communication skills. The projects are designed to solved by student teams, who are told they are acting as consultants on the project posed. These projects are open ended problems with multiple possible solutions and are designed to emphasize interpretation of numerical results rather than pure numerical computations.

Both the scope and nature of the projects can be seen in the sample project that is given in Appendix A. Appendix B contains a sample grading rubric for the report component of the projects, which is worth 30% of the final project grade. While the reader may view the instructions as *"handholding"*, it should be noted that the students typically view them as *"vague"*. It is essential that the instructor balance the student need (or desire) for explicit instructions with the learning which comes from struggling with:

- Choosing the best approach/theory to tackle the problem;
- Making appropriate assumptions; and
- Evaluating (often conflicting) results.

It also should be emphasized that the link between the theories and concepts presented in class and the real world projects ***is not obvious to the students!*** Some students fail to see any connection between the homework, exams & the projects even when links are made explicit in the class. Similarly, we have found it necessary to emphasize the links between the content of other courses (past, concurrent, and future) and what is happening in our classes and class projects.

STUDENT PERCEPTIONS

Students in the course

At the end of the semester, students are surveyed regarding the course; including questions related to how much the course met the specified ABET outcomes and how different course components enhanced their learning of the material. Table 1 shows the results of the questions regarding ABET outcomes from the Fall 2006 in CVEN 345 Theory of Structures. In general, students agree that the course does add to their knowledge and skills in the specified ABET outcomes. In the dynamics course, students were somewhat neutral in the outcomes related to communications and computer skills. Typical comments from students about the projects in the structural analysis course include:

- "I seriously enjoyed doing the project. I felt as though I could show my understanding of the class in these projects."
- "The projects helped tie the material together."
- "I could see how a structural engineer would actually do this in practice."
- "Being able to explore different truss configurations was very interesting. It really gave me a feel for these systems and how loads get transferred."

Table 1: Student Perception on Course Adding to their Ability in Specific ABET Outcomes

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ability to apply knowledge of basic mathematics, science, and engineering				
17	29	3	1	0
Ability to function on multi-disciplinary teams				
21	26	2	0	0
Ability to formulate and solve civil\ocean engineering problems				
18	17	8	4	3
Ability to communicate effectively (verbal & written)				
10	20	16	2	2
Ability to use computers to solve civil\ocean engineering problems				
16	29	3	2	0

Not all students were positive about the projects and the following comments illustrate two common themes:

- "The projects was a distraction from learning the material I needed to know for the final"
- "Most of the assignments and projects were confusing and ill-prepared. Students had trouble figuring out what it was we were supposed to be doing."
- "The projects were frustrating because we didn't always know exactly what we were supposed to be doing. I did however learn a lot by struggling through them."

The first comment illustrates how some students are focused on exams and the grade, rather than on learning the material. The second comment is related to the discomfort most students feel when first presented with a realistic and open-ended problem.

Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that these are courses where they see how the material relates to the practice of civil engineering, and that these connections enhance their learning of the material. Table 2 shows the student's responses to questions regarding course overall.

Table 2: Results from Final Course Evaluation in Fall 2005

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Course emphasizes understanding vs. memorization				
36	10	2	1	1
Use of CE examples played a large role in learning the material				
15	26	7	1	1
Projects added to my understanding of course material				
15	27	4	3	1
I have learned a great deal in this course				
25	21	4	0	0

The one consistent complaint from the students is the time required to pull the projects together. Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that these courses are one where they see how the material relates to the practice of civil engineering. The results from three questions related to the project are presented in Table 3.

Table 3: Student Perception on How Projects Enhanced the following

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Critical Interpretation Skills				
36	10	2	1	1
Connection Between Concepts				
15	26	7	1	1
Motivation for Course Concepts				
15	27	4	3	1

Former Students

The addition of these projects is providing an important tie between the introductory structural analysis course and the follow-up design courses as well as work done in engineering internships. A student from CVEN 345 in a previous semester sent one of the authors the following email:

"I just wanted to let you know that, though we complained about the work involved, the project you assigned in 345 was exactly what I ended up doing this summer at my internship. It really helped that I had already done something of this nature!"

Students in the senior level reinforced concrete design were surveyed to determine student perception substantially after the conclusion of the structural analysis course. Students in the concrete course had taken the structural analysis course at various different semesters (ranging from Fall 2003 to Summer 2005) and under at least four different instructors. They were first surveyed as to how the structural analysis course they took met the specified ABET outcomes, and the results are shown in Table 4.

In the final course evaluation, students were also asked how the project in CVEN 345 aided in their understanding and ability to complete the reinforced concrete course project. The survey asked how strongly they agreed with a series of statements regarding the structural analysis course project. The results are shown in Table 5.

Table 4: Reflecting back on CVEN 345 and its ABET Outcomes

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ability to apply knowledge of basic mathematics, science, and engineering				
17	29	3	1	0
Ability to function on multi-disciplinary				
21	26	2	0	0
Ability to formulate and solve civil\ocean engineering problems				
18	17	8	4	3
Ability to communicate effectively (verbal & written)				
10	20	16	2	2
Ability to use computers to solve civil\ocean engineering problems				
16	29	3	2	0

Table 5: Impact on Structural Analysis Project in their Ability to Complete Senior Reinforce Concrete Design Project.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Previous exposure to determining load patterns and demand envelopes helped you in completing the first part of the design project				
13	15	5	2	0
Projects in CVEN 345 helped you in this course?				
8	16	7	2	1
The project in CVEN 345 added to your skills in writing technical reports				
9	10	12	4	0
Working in teams was an important skill in successfully completing the project				
20	19	2	3	0
The required evaluation of the system response in the projects help your critical interpretation skills				
10	16	13	3	0
Previous use of an analysis software package (such as Visual Analysis) help you in learning ETABS				
9	18	7	6	1

Typical positive comments collected include the following:

- I enjoyed the CVEN 345 project because of its application to "real world" problems. Although each step of the project was challenging, this project taught me successfully taught me how to completely analyze a structure. By talking to my peers in other sections, I realized that completing the project was much easier when the student had the professor that actually wrote up the project.
- I learned a great deal about determining applicable loads, load patterning, and tributary area. The project allowed me to fully understand the endless design possibilities. The project was wonderful in that it tested our grasp of all of the CVEN 345 course material.
- The project is very similar to the concrete as far as the thought process required, but the CVEN 444 project takes it a step further and requires the actual design of the members in the structure.
- The project that has helped me the most on this current project is the one from CVEN 345. I not only learned how to correctly analyze a structure, I also learned how to write an effective report.

The first comment above also points to a source for some of the negative comments. The instructors actively involved in developing the course projects typically are more explicit about linking the project tasks to the different course topics. As such, students in those sections see the links and motivation behind the required activities. However, other instructors were not as explicit about demonstrating those connections. So while the same material was covered and the same project was completed in different sections, students had very different experiences and perceptions of the projects. Some typical negative comments are:

- It was very tedious and confusing. Mostly busy work.
- The project was never well explained and we didn't get much help so I don't believe I learned much because we just did what we thought was right
- The project was not easy to comprehend what we were doing until we were on one of the last parts...this led to not understanding the project fully in the end.

STUDENT PERFORMANCE IN LATER COURSES

The first part of the course project in the senior concrete design class is the computation of the force and moment demands on a frame structure. Students are required to determine the appropriate loads, establish load patterns for the live loads, and develop the envelopes to capture the worst-case scenario over all patterns and factored load combinations. As such, this part of the project is very similar to the final project in the structural analysis course, CVEN 345. The CVEN 345 project also asks students to consider how they could improve structural performance by changing the structural system. As they are using finite element analysis software, they accomplish this through trial and error, and in the process become exposed to thinking from a design perspective.

The course project for reinforced concrete design involves the member design of a multi-story office building, starting from the calculation of member demands. In previous years, the class average on the analysis component of the project has been traditionally low. For example, in the Fall of 2000, that project component had a class average of 79, with the highest grade being a 90. In the Fall 2005 semester, under the same instructor as in the Fall of 2000, the average on the same project component had risen to a 90, with the highest grade being a 100. Table 6 provides the results of how different student groups performed in the concrete design course in Fall 2005. The groups are: (1) the entire class, (2) students who completed the structural analysis course with the project, and (3) students who did not have the project in their section of CVEN 345.

Table 6: Breakdown of Student Performance in Undergraduate Concrete Design.

	Entire Class	Project Experience in CVEN 345	
		Yes	No
Number of Students	57	35	22
Average on Exams			
Mid-Term Exams, %	76.7	80.18	74.11
Final Exam, %	76.2	84.18	69.87
Average Project Grade			
Analysis Project Component, %	89.38	92.7	86.94
Entire Course Project, %	92.52	95.19	90.44
Course Grade			
100 point scale	83.77	88.98	79.70
4 point scale	2.98	3.40	2.66

As expected, prior exposure to performing a demand analysis on a frame improved the students performance on that component of the project. While that group still had a better overall performance on the project, the gap between the groups became smaller. The group previous project experience also did better in the class overall, including a better performance on the exams, which also tested their ability to tackle open-ended design problems. The final exam for this course was an open book take-home exam that had individualized problem parameters.

CONCLUSIONS

To be successful, incorporating realistic project into a course requires that instructor makes explicit ties between course topics and the project tasks and outcomes. The authors strongly recommend emphasizing to the students that projects are not meant to serve as tools to master basic concepts, rather they serve to tie different concepts together and see how they are used to solve realistic concepts." The weight given to course projects in computing final course grades can aid in this if the percent is comparable to that of a midterm exam or course final.

We also believe that the incorporation of open-ended, real-world, design-like projects has tremendous pedagogical value. At the very least, it demonstrates to students what they do and do not know. At the best, it provides the context to make the theory learned in the classroom meaningful. The bottom line is summarized by the following CVEN 345 student quote:

"Overall this class introduced me to a more realistic approach to real world problems. It made me realize the importance of clearly understanding physical models and their behavior to certain applications."

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APPENDIX A – ROOF TRUSS PROJECT

You are the consulting engineer on a project and are being asked to evaluate the roof designs for a small warehouse. The primary design being considered is composed of Pratt roof trusses that are uniformly spaced at every 15 feet. A drawing for a <u>similar</u> truss is given in Figure 1. However, your truss has 6 equal width panels as opposed to 4. Additionally, it must span a horizontal distance of 42 feet, and the overall height at the peak is 18 feet from the bottom chord. All elements in this preliminary design have uniform cross-sections of 4in^2. The second design being considered, a Howe truss, is utilized to support the same roof. In addition to evaluating these two proposed designs, your design firm will also propose a third alternative solution.

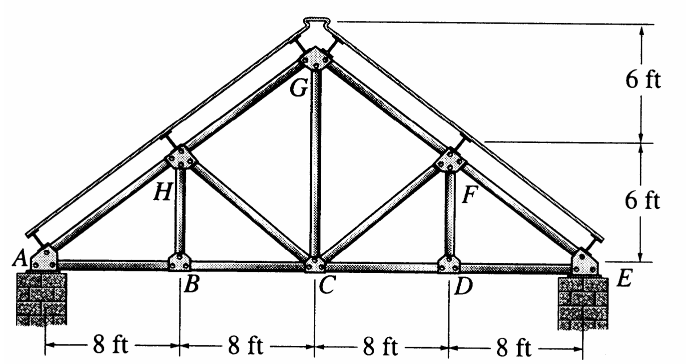

FIGURE 1
ILLUSTRATION OF PRATT TRUSS

<u>Loading Information:</u>

- The deck, roofing material, and the purlins have an average weight of 5.6 lb/ft2.

- The truss members are made of aluminum, with a weight of 165 lb/ft3.
- The building is located in New York State where the anticipated snow load is 25 lb/ft2 and the anticipated ice load is 12 lb/ft2. These loadings occur over the horizontal projected area of the roof and act vertically downward as governed by gravity.
- The anticipated roof live load for Flat or Pitched roofs is given by ASCE 7-02:

  Excerpt from ASCE 7 included in student handout
- For the present, wind and earthquake loads will be neglected.

Support and Member Connectivity Information:

The truss has bolted connections to the supporting load bearing walls. However, the connection on the right side is designed to allow horizontal translation to occur at that joint. The purlins are angled along the top members of the truss and are connected such that both horizontal and vertical force components can be transferred to the truss.

Tasks:

a. Determine the concentrated forces applied by the purlins on the truss due to the dead load, snow loads, ice loads, and roof live load individually. Identify the distinct factored load combinations applicable to this system (given the applied loads some factored combinations may end up looking identical when non-applicable loads are removed). Look carefully at the handouts from ASCE 7-02.

b. Use Visual Analysis or other structural analysis software program (such as RISA) to analyze *both* truss types. Enter individual unfactored loads as individual Service Cases in Visual Analysis. Then create a Factored Case for each applicable factored load combination identified in part (a). In this manner, you allow the software to scale and combine the different load types. Perform a First Order Static Analysis on all the factored combinations. Document your results for both trusses using the clearest way to convey the information (the method is up to you).

   Additional detail included in student handout

c. Evaluate the numerical results. Some questions to consider: What are the peak tensile and compressive member forces? What is the maximum vertical deflection over all the joints in the truss? At what joint does the maximum deflection occur? (You must answer these questions for both truss types). Do these values seem reasonable?

   Additional detail included in student handout

d. Compare the behavior of the three truss systems you have analyzed. What are the consequences of the change in truss type? Be sure to compare and discuss the differences member forces (both magnitude and tension/compression analysis – what possible failure mode happens in compression that may cause problems? So is it better to have members in tension or compression?) and in the maximum deflections for the two truss types. You may and should consider other considerations such as constructibility and cost. Which structural system would you recommend and why? How do you expect consideration of the lateral loads (wind and earthquake) to change your results? Assume cost for the truss is proportional to member volume (length * cross-sectional area) and number of connections. You may also wish to consider peak clearance under the roof as a performance criteria.

Appendix B – Grading Rubric for Project Reports

Students received a blank rubric before the project reports were completed and a rating on each of the following items covering the range of fail (0), poor (3), fair (6), good (8), excellent (10 points)

ORGANIZATION		
	Title Page Complete	
	Table of Contents w/ page numbers	
	All pages appropriately numbered	
	Sections presented in right order	
	Figures, tables, Eqns. numbered	
	Figure/tables have captions	
	Figures, tables referred to in text	
	Calculations in appendix	
WRITING		
	Grammar & Mechanics (ex: spelling, sentence fragments, verb-subject agreement, run-on sentence…)	
	Style (ex: consistent use verb tenses, main ideas emphasized, well structured presentation of ideas, logical connections between sections…)	
CONTENT		
	Executive summary	
		Self-contained?
		Brief overall description of problem and solution approach?
		Includes main conclusions?
	Introduction	
		Presents overview of problem
		Discusses main issues to be addressed
		Effectively outlines in text form what will be presented
	Problem Description	
		Problem accurately described
		Assumptions given and evaluated
		Drawing of system clearly labeled
		Solution procedure described
		Relevant theory presented
	Results	
		Clearly presented
		Effective format used (tables, graphs…)
		Explained in text
		Explanation logical and consistent
		Refer to supporting calculations
		Compared with expected results
		Emphasize main implications
	Conclusions and Recommendations	
		Brief summary of results & issues
		Clear recommendations
	Appendices	
		Separated based on content
		Calculations easily followed