Sophomore-Year Project Design in Mechanics of Materials

Kevin G. Sutterer, P.E.
Rose-Hulman Institute of Technology

Introduction

Civil Engineering students at Rose-Hulman Institute of Technology (R-HIT) begin to learn open-ended, project-based design in a first year civil engineering design course where groups of 3-5 students work for outside clients on a simple civil engineering project. In their Junior year, students participate in a three-course structural engineering sequence (*1*) where they design a proposed 2 to 3-story campus structure, beginning with design of foundations and preparation of a geotechnical report, and followed by a concrete frame design and steel frame alternative in two subsequent courses. As seniors, civil engineering students work in teams of 3-5 students on a year-long design project for an outside client that produces a quality "real world" engineering work. In other junior and senior year classes, students also complete projects of varying complexity. However, formal design of an engineered system has not been a part of any of the required courses for civil engineers in the sophomore year. Rose-Hulman's academic year uses the quarter system and pushes students to begin engineering course work by the end of their freshman year. By the Winter Quarter of their sophomore year, civil engineering students are enrolled in Mechanics of Materials, having already completed course work in Engineering Statics and Engineering Dynamics. Thus, by the middle of their sophomore year, they have acquired most of the tools necessary for some simple quantitative engineering system design.

By the sophomore year, engineering students can also begin to experience "burnout" with their courses and often express a desire to get on with some "real engineering." Retention can be a particular challenge at this stage of engineering students' college career. Regardless of whether retention becomes an issue, student motivation can be a problem. Students who are excited about the work they are doing are usually better learners, so poorly motivated students taking fundamental engineering mechanics courses provides a poor foundation for learning specialized engineering design in the junior and senior year. The author has also observed that incoming civil engineering juniors are not well prepared to tackle the open-ended design work that is expected in their upper division courses. This paper describes the author's ongoing effort to excite and educate civil engineering sophomores about the engineering design process by challenging them with an open-ended structural system design as part of their Mechanics of Materials course. It should be noted that although the course described herein is mostly populated by civil engineering students, 15-25% of the class also often consists of mechanical engineering students who are taking the class out of sequence with their mechanical engineering curriculum.

The author has found the "backward" design process described by Wiggins and McTighe (*2*) to be helpful in curriculum review and revision. Backward design consists of a staged approach to curriculum design, consisting of 1) identify desired results, 2) determine acceptable evidence, and 3) plan learning experiences and instruction. To identify desired results, curriculum designers should identify knowledge associated with the subject being learned and prioritize that knowledge in one of three types (*2*): (a) "enduring" understanding, (b) important to know and do, and (c) worth being familiar with. Acceptable evidence that the desired results have been achieved requires assessment of learning. Assessment may be one of three general types: content-focused quiz and test questions, open-ended problems that require critical thinking, and authentic performance tasks and projects. Assessment measurements may include quantitative data, qualitative observations or comments, and reflective statements by faculty and students.

This process is a good structure for curriculum revision, but meticulous completion of every aspect of each stage of course planning can significantly delay or prevent putting the work into practice. In unfunded work, safer and more manageable curriculum revision occurs in an iterative manner, wherein the faculty puts into action course modifications that are not likely to hurt traditional learning but are on the road to a defined goal. The first and every course iteration includes careful assessment. Based on this assessment, additional modifications can be made, so that over a period of years the course evolves to meet the desired results. Throughout the process, the faculty continues to give traditional quizzes and tests of the same high course value they would have in a traditional course, and the expected topic coverage and difficulty of those assessment tools is kept the same, even if less class time is assigned to the topics. In this way, the faculty can assure that valued traditional basic knowledge is not sacrificed while elevating the level of work completed by students. This modification of backward design is especially suitable for unfunded work for courses at research universities where faculty have much less time for major course revision. Of course, in some cases, minor changes are not possible and a "leap of faith" into a more dramatic course modification is necessary. This is not recommended as a first step in curriculum revision but rather as a step much later in the process, if at all.

Desired Results

The desired results of the author's modifications to Mechanics of Materials are:

- No reduction in student knowledge of the theory, principles, and tools typically learned in traditional Mechanics of Materials, as measured by traditional tests and quizzes.
- Student understanding of one type of authentic engineering system design.
- Excite and motivate students to learn as much as possible about fundamental mechanics of materials and its role in engineering design.
- Familiarize students with open-ended design work in their courses so they begin to understand the necessity to take ownership of their learning and work completion.

Acceptable Evidence

Acceptable evidence that the desired results are achieved is being measured using four different assessment tools.

- Traditional quizzes and tests of equal difficulty and coverage as those given before curriculum revision are used to assess whether students are still learning mechanics of materials at the three lowest levels of cognitive learning (*3*): knowledge, comprehension, and application.
- Faculty evaluation of assigned open-ended stages in their design, and of student team completion or partial completion of the authentic project, is used to assess whether

students are developing better understanding of the design process. This reflects higher learning at the analysis and synthesis levels of cognitive learning (*3*).

- Formal learning assessments completed by the students include official R-HIT end of quarter evaluations and course-specific student surveys and reflective comments. These assessments include numerical rating of different aspects of the course and written comments on learning, the course itself, and quality of instruction. Informal assessments are completed by student interviews after course completion and in the ensuing years of college study.
- Faculty reflection on student learning is an important component of the assessment. Formal reflection occurs through written discussion after review of the other assessment results upon course completion, but informal reflection continues into planning for the next offering of the course.

Learning Experiences and Instruction

Within the backward design framework of Wiggins and McTighe (*2*), traditional Mechanics of Materials topics can be assigned to the categories of a) enduring understanding, b) important to know and do, and c) worth being familiar with. Without categorizing topics, faculty may assign all topics similar, if not equal value due to their own scholarly value of the knowledge. It is appropriate to consider the value of the topic to the user, rather than the instructor, however. Each topic can be ranked better if considered in terms of its value to engineers with a Bachelor's or Master's degree, and while recalling that some topics will be covered in more detail later in the curriculum. This assignment of topics is important not so much to prepare for elimination of topics, but to assign how much time will be spent on each, and in guiding selection of appropriate projects. Category a) topics should be given more emphasis in the course than category c). In the course described here, introduction to the open-ended design process and synthesis of a variety of Mechanics of Materials topics into design of a machine or structure was assigned category a) status. A significant open-ended design of an authentic machine or structure was thus deemed suitable as a concluding work for students in Mechanics of Materials.

Open-ended project work requires class meeting time for student groups to work under the mentored guidance of the faculty. This reduces the amount of class meeting time to cover traditional mechanics of materials topics. Project work also requires "homework" time that thus takes away from the time students may invest in working traditional textbook problems. To facilitate complete topic coverage in less time, an accelerated course format has been adopted for the first half of the course. Within the first half of the course, approximately 75-80% of the course topics are covered in primarily traditional lecture format. Topics in the first half of the quarter are selected to introduce students to the theory and tools they will need to work on their project in the second half of the quarter. The remaining 20-25% of the course topics are covered at the same pace in the second half of the quarter, with the remainder of the class time (about 35% of all class meeting time) assigned to project work. Homework is assigned for all topics covered, but the total number of problems is reduced to accommodate the faster pace. Students are expected to do less of the simpler textbook homework problems and instead work on one or two moderate difficulty problems that illustrate most of the concepts covered. Project work is planned so challenging problems using the same concepts will come during the project work. Some lower level cognitive learning is removed from planned lectures and left to students to complete on their own through reading and "need to know" situations on the project and in preparation for tests. This motivates students to take ownership of their learning. Students also participate in 3 to 5 "lab homework" assignments which require them to do a simple lab exercise as if it were just another textbook homework problem. These exercises help them to visualize behavior in a real setting and actually observe failure and deflection of materials.

The faster pace puts students under stress, and those that have difficulty with the concepts can be left behind without mentoring. In this course, the first class test is difficult and early in the quarter to remind those students who have not taken ownership of learning that they had better do so quickly. The faculty also maintains an open door policy to assist students with questions outside of class, encourages struggling students to work on their assignments during the day in a room nearby so they can pop in with quick questions, and conducts a review session late in the evening before each test to help students clarify final difficulties they may have with some topics before the test. In a research university setting, some or all of these extra activities may be conducted with the aid of properly trained and motivated graduate students.

Project selection criteria are simple, though finding projects may be a significant challenge in the future. The project must have the potential to be a real constructed system and must require working with connection design and use of a majority of the primary elastic design topics addressed in Mechanics of Materials. The project must also entail estimation of loadings and should consider an uncertain range of potential loadings that may occur in use. The project does not have to be completed by students, as long as it is simple enough to allow them to understand what they would do to complete the design. It is crucial the project be something the students can value and believe is important, so the students are positively motivated to learn and understand the design process and come to understand (not just know) the fundamental concepts and design tools learned in Mechanics of Materials. Project work submittals are in strictly scheduled stages, beginning with conceptual sketches, loading estimates and attempts at static analysis; followed by design of major member cross sections; connections designs, and finally a final team submittal of the completed work. Sketches and "by hand" computations are encouraged when they will save students time, and use of any type of analysis software is discouraged. Spreadsheet or math software solutions programmed by each team independently are acceptable. Since the project is typically too difficult for student teams to complete, students on those teams who finish early are tempted by the faculty with extra credit opportunities to carry the design farther. This opportunity appeals particularly to those students who are struggling in the class, and they are thus encouraged to learn better and also work harder to finish early so they can pursue extra credit work. Extra credit may be submitted by part of a team or by the entire team.

In the first course offering (Winter 2000-2001), ten different student teams designed a load frame that could test steel, concrete, timber, and composite beams up to 14 feet long for the structural engineering laboratory at Rose-Hulman. The students knew the frame was needed for planned work in their junior and senior courses, and were assured that funds would likely be available to build the load frame the following summer. Student enthusiasm for the project was high, and student designs were used by the author to guide frame design and fabrication in the summer of 2001. Juniors arrived on campus in the Fall of 2001 to find "their" load frame sitting in the structures laboratory (Figure 1). For the course in Winter 2001-2002, another load frame design was obviously not appropriate. The author considered design of a floor crane for moving beams around in the structural laboratory, but existing floor cranes on campus would be easily accessible to the students and could be easily copied in their design effort. A previous civil engineering senior design project at Rose-Hulman involved setting up software and doing assessment for a lifting crane inventory at the Crane Naval Surface Warfare Center in nearby Crane, Indiana. Over 100 cranes remain to be assessed for that inventory, and the assessment of these cranes by sophomore teams was also considered. However, limitations in student access to the facility, the analysis versus design nature of these projects, and the need for the faculty to carefully validate each design for the safety of Crane personnel eliminated this project for current consideration, though it may again be considered as the course develops. A third desirable alternative involved industry collaboration on projects through one of R-HIT's industry collaboration initiatives, but in the interest of evolving the course slowly to make sure traditional learning is not lost due to possible industry client demands, this alternative has also been delayed until later.

Figure 1. Load frame constructed by the department that was a result of the project work described.

The project ultimately chosen for the 2001-2002 course is to design a steel bridge for the annual ASCE student chapter steel bridge competition. The project is appropriate for the civil engineer-dominated class, is sufficiently complex to challenge the students, and is valued by most of the students as they follow or participate in the actual ASCE student chapter steel bridge design and fabrication, independent of the course. None of the project designs completed in Mechanics of Materials are to be used for the student chapter's actual steel bridge, but since the bridge team members are asked to help mentor the class, both the steel bridge team and Mechanics of Materials students will benefit. A limitation to this choice of project is that the student teams will not be able to assess deflection of their design, which is a crucial part of the actual competition. So for the class project, the faculty is having the students design their bridges for a specified factor of safety versus yield, and deflection will be either an extra credit opportunity or excluded altogether. The project work is under way at the time of this paper.

Assessment Results

The following assessment comments are based on the findings from one offering of the described course in the Winter of 2000-2001. The course is still in development, but the initial results have been promising. The author has observed that with class sizes of 25-45 students, class personality and enthusiasm for different types of learning can vary significantly. There is now some qualitative evidence that the 2000-2001 sophomore class was more oriented towards this type of learning than typical classes, though that could be due partly to the course changes described herein and due to some changes in their civil engineering freshman design course. The faculty and some colleagues have observed the current sophomore class has a different personality and class chemistry than the class in 2000-2001, so student response to the second offering of the course should be insightful.

On similar-content, similar-difficulty tests, quizzes, and the final exam in the first year of this class (Winter 2000-2001), student performance was slightly better than in previous years, but within the normal deviation for the class from year to year. Thus, while there did not appear to be evidence that learning of traditional Mechanics of Materials knowledge was sacrificed, no definite assessment of whether learning was enhanced can be made with the results from only one class.

Faculty review of student work activity in 2000-2001 indicated students were excited about the project and genuinely were seeking understanding of the application of concepts. A variety of students, ranging from strong to weak, worked independently or together on extra credit, and clearly refined their design skills through that extra activity. Observation of student work effort was made during class meeting time, outside of class time when observable in the Civil Engineering student lounge, and as evidenced by student visits during faculty office hours to answer questions. Evaluation of staged design submittals (sketched concepts, statics computations, primary members design, connection design) and the final design submittal clearly indicated the student groups had a better understanding of engineered system design than previous classes in Mechanics of Materials. An additional observation is that the author frequently saw "the light go on" (sometimes referred to by the author as an engineering revelation) in discussions with individual students or teams wrestling with a design challenge. The frequency of this occurrence was much higher than when the course was taught using traditional methods. The in-class mentoring in lieu of traditional lecture thus appeared to be highly beneficial to student comprehension, helped keep faculty out-of-class time minimized, and carried the added bonus of faculty satisfaction that comes from observing an engineering revelation. Project work in 2001-2002 is under way at the time of writing of this paper, so no assessment of that second offering is possible at the time of preparation of this paper.

Student surveys, both using the required R-HIT end of quarter survey and course-specific surveys, indicated the class strongly favored continuation of this course format, although comments like "Open ended design would be better if you would give us the input loads, suggested member sizes, and tell us the final answer" were not uncommon. While such comments are amusing, they also indicate some students did not understand what open-ended means even after doing the work. Students also felt the workload was too high, but generally felt the extra time was worth the challenge of doing the project. Open-ended project work definitely increases the stress level for many students, and also sets up a class meeting structure that is much less organized. These characteristics of the course earned low marks on quality of instruction and overall course rating, a fact that should be noted by untenured junior faculty considering this type of learning. This is typical of open-ended project work, particularly in the first 3-5 years of implementation. In the final analysis of assessment findings, student support for the inclusion of "real engineering" outweighed dissatisfaction with workload. Finally, open-ended project work is a love-hate choice for most students. Students either strongly like or strongly dislike the process. This was reflected in the range of comments from the assessments.

Faculty reflection on whether the course achieved the desired results was promising. In addition to the above findings, juniors who have completed the course have demonstrated improved skills and a more positive attitude about open-ended design in 2001-2002. Last year's student support for the course was the strongest the author has had in the first offering of any course modified to include a significant open-ended project component. However, in planning for 2001-2002, the author felt the course must continue to consist of projects that the students could value and imagine truly being built. This presented a dilemma when seeking industry partners or real on-campus projects using elastic materials. The ASCE steel bridge contest seems to provide a viable solution, but industry partnership seems to be a more suitable goal for future implementation.

Lessons Learned

1. Students can do significant engineered system design with knowledge of engineering statics and suitable introduction to mechanical design principles and tools. Motivation of the students to reach a "need to know" status will go far to improve learning.
2. Much of the material traditionally learned in design courses through end of chapter homework problems can be learned more efficiently through planned, open-ended projects, and while doing this learning, students are also learning more about the design process and working harder on what they refer to as "real" engineering.
3. Students will resist open-ended project based learning because of the higher stress level and because it makes them "think harder."
4. Grading of open-ended project work is generally more time consuming than grading of traditional homework assignments. Based on past experience, the author is optimistic that grading time will diminish as his evaluation processes develop in this course.
5. Group work is beneficial but risky. Inevitably, some students do not carry their share of the workload, so teammates step forward to do more towards completing an acceptable project. The penalty for failure to perform in "real world" teams is higher (loss of job or income) than for failure to perform on teams in the classroom. Further, students are not likely to be as tough as they should be in assessing a teammate's weak performance. So

group work can permit some students to get a higher grade on their project effort than they deserve, and cause other students to get a lower grade than they deserve. Project evaluation and assignment of project value in the course must minimize abuse of this situation as much as possible.

Bibliography

1. Sutterer, K.G. and Descoteaux, T.J. (2002) "Before Senior Design – Integration of Project-Based Learning in a Multi-Course Structural Engineerings Sequence," accepted for presentation in session 2215, ASEE Annual meeting.
2. Wiggins, G. and McTighe, J. (1998) *Understanding by Design*, Association for Supervision and Curriculum Development, Alexandria, Virginia, 207 pages.
3. Bloom, B.S. and Krathwohl, D.R. (1965) *The Taxonomy of Educational Objectives, The Handbook of Educational Goals. Handbook 1: Cognitive Domain.* McKay, New York.

Biographical Information

Dr. Kevin Sutterer is an Associate Professor in the Department of Civil Engineering at Rose-Hulman Institute of Technology. Prior to joining Rose-Hulman, he was a faculty at University of Kentucky. He has also worked six years as a full time consulting Geotechnical Engineer for Soil Consultants, Inc. of St. Louis, Missouri.