Immersive Group Projects for First-Year Civil and Environmental Engineering Students

Lawrence G. Cartwright, David A. Dzombak, James H. Garrett, Jr., Chris T. Hendrickson, I. J. Oppenheim, James M. Thompson, and Jeanne M. VanBriesen
Carnegie Mellon University, cartwright@cmu.edu, dzombak@cmu.edu, garrett@cmu.edu, cth@cmu.edu, ijo@cmu.edu, jimt@cmu.edu, jeanne@cmu.edu

***Abstract* - The engineering curriculum at Carnegie Mellon University features substantive first-year courses taught within each department, and requires students to take two such courses before declaring their major. The course in Civil and Environmental Engineering treats three specialization areas, and engages students with immersive, hands-on, group projects in each area. The projects fulfill multiple educational objectives: students apply engineering science material conveyed in lectures and homework exercises; groups face numerous engineering design decisions involving tradeoffs; students experience the dynamics of group work; and, groups must communicate through written reports and oral presentations. Each project involves hands-on activities conveying the questions of engineering interest in tangible terms. The environmental project addresses the reaeration of a body of water, modeled by the appropriate first-order differential equation. The construction planning project requires assembling an object with components from competing suppliers with different unit costs, modeled by Gantt charting and/or by deterministic queuing. The structures project features a truss design requiring tradeoffs between strength and constructability, evaluated by its failure probability, and tested by the weight of the instructor. At the conclusion of each project the class observes the range of solutions presented by the different groups, at which juncture the instructors provide an overview.**

Index Terms – Design decisions, Group projects, Hands-on experience, Technical communications.

INTRODUCTION

In the early 1990s the engineering college at Carnegie Mellon University introduced changes to the undergraduate curriculum, with particular attention to first-year courses. One goal was to invert the student experience by creating encounters with engineering decision-making at the earliest possible date. Related goals included making early connections with the other required first-year courses in calculus and physics, making the students part of the engineering community, and providing those students with experiences of sufficient depth to create enthusiasm for their university career as an engineering student. The first year courses are the mechanisms devised to fulfill those goals. Each department teaches its own such course in each of the two academic semesters. The curriculum requires each student to take two such courses, after which the student declares a major. The first-year courses, across the college, are demanding and substantive. A further aspect of the curriculum revision, extending to all years of the program, is to minimize the number of required courses and maximize the number of free elective choices.

Another goal addressed in the curriculum revision is to balance the overall load on engineering students. The first-year courses at Carnegie Mellon carry 12 units of effort, equivalent to 4 credits, meaning that the total student workload should average 12 hours per week. The course meets 4 hrs/wk, and therefore additional effort demanded from students in homework exercises, study time, and project activities should not exceed 8 hrs/wk. Designing syllabi and projects to respect that limit can be achieved, but requires careful attention by the teaching staff.

In the Department of Civil and Environmental Engineering, the first-year course treats three specialization areas within the discipline, and centers each third of the course around an immersive, hands-on, group project. Considerable effort has gone into syllabus design in order to deliver substantive content to the topics treated in lectures and exercises. One cannot simply shorten or scale down the traditional treatment of a topic, but with deliberate attention the right balance has been achieved; it is noteworthy that the syllabus has evolved by continuous improvement through the collective effort of numerous faculty members. Not surprisingly, even greater care has been required to develop successful projects, which are the topic of this paper.

COURSE OVERVIEW; ROLE OF GROUP PROJECTS

An instructor has an obligation to deliver the course in fulfillment of ABET/ASCE course outcomes and in compliance with the course description within the approved curriculum. However, the detailed syllabus, the topics to be studied, and the projects to be employed are established by the instructor. In practice, different instructors generally base their syllabi and project choices on those developed in preceding semesters, and then introduce incremental changes in a process of continuous improvement. The course is typically taught with a sequence of (roughly) ten handouts and ten homework sets, and an instructor will generally revise a number of them each semester. It is also typical for an instructor to conceive an idea for a new project after one or two semesters of experience, and therefore individual new projects are introduced roughly every two years. It is also possible for an instructor to choose a different specialization area and develop it as a portion (one-third) of the syllabus. This paper describes the breakdown most commonly used: environmental engineering, construction planning, and structures. However, at other times the topics of sustainability, hydraulics, or transportation have been bases for a portion of the syllabus and for a project.

The first-year course is of broad importance within the curriculum, spanning many of the skills and abilities identified in the ABET/ASCE accreditation process. Skills A, C, D, and G are designated to be primary outcomes, and skills E, F, and I are designated to be secondary outcomes. Outcomes F (professional and ethical responsibility) and I (life-long learning) are addressed in teaching units and exercises within the course, while all other outcomes are clearly reflected in the three immersive projects.

The projects fulfill many purposes, including the following:

- Providing students with hands-on exposure to the properties of engineering interest that they treat in lectures and exercises;
- creating a thought-provoking scenario somewhat representative of the real world;
- requiring a number of specific tradeoffs to be made when addressing the problem as posed;
- requiring a number of specific choices to be made between alternatives;
- demanding the application of new material treated in the course lectures, as well as material from mathematics and physics courses, as well as material from other background dimensions;
- inviting discussion and debate, within the project group, over plausible choices and decisions;
- placing students in a project that requires working as a group, exposing them to the organizational and interpersonal demands of such work;
- requiring intra-group communications, and then requiring multiple written communications to the project supervisors;
- and, requiring group presentations to the full class community.

Under the schedule constraints of this first-year course, the activities on each project must be compressed into a time period no longer than three weeks, with an additional week after the project conclusion in which the groups would write their final reports. To respect the constraints on student loading, the activities on each project, including report writing, should demand no more than 20 hours of effort from each student. These constraints can be satisfied, but this requires careful effort by the instructional staff to design appropriate projects.

The resulting projects generally share the following characteristics:

- The project creates a physical environment in which dimensions, activities, and time are scaled to create an understandable and interesting scenario, while retaining the same engineering behavior as the prototype in the real world.
- The project requires the student group to make some specific design choices that exemplify realistic engineering decision making. In general, those choices are expressly identified in the problem statement or are strongly suggested in the dialogue with which the instructor introduces the problem. (Note also that many engineering problems admit multiple solutions, several of which might be equally justified.)
- The project generally contains some significant tradeoffs, often exaggerated by the unit costs and constraints set by the instructor. The group must reach a level of project involvement that enables them to recognize, assess, and analyze those tradeoffs. The group must then go through a challenging process to reach decisions about those tradeoffs, which might be argued from more than one point of view.
- The projects are designed to be executed within specific time limits, and project activities are scheduled and constrained to respect the demand on student effort.

The course typically enrolls between 60 and 75 students, and the regular group size is four students. Therefore, each project is generally undertaken by 15 to 18 student groups.

ENVIRONMENTAL ENGINEERING

The project involves reaeration of a group of six “lakes” after partial or total depletion of dissolved oxygen (DO) to determine whether the lakes can be restocked with fish on the project end date; the lakes are large water vessels in the project room that have been chemically depleted of DO. The depletion condition and the reaeration behavior is different in each lake, and therefore the class as a whole sees six different environmental problems, while each student group examines only one lake.

Lectures and exercises introduce the topics of concentration, flow, mass balance, and mass balance with constraints. The lectures then address first-order differential equations, examining exponential growth, logistic growth, and exponential decay. That last solution form, exponential decay, models the reduction of DO deficit with time during reaeration, and is then applied in this project. Each group samples the DO in one lake over multiple days, within a sampling period that ends well in advance of the project end date; the group must extract a rate constant and then predict the DO on the project end date.

Students measure DO using a commercial test kit with single-use vials, but each group is provided only five vials to sample DO over the project period. The group must devise a sampling strategy, must be prepared to change their strategy in response to their measurements, and must weigh the confidence they have in their data. The project scenario poses a realistic incentive to recommend an earlier end date if the group is confident that a satisfactory DO level will be achieved by that earlier date, but such a step demands a risk-reward discussion. The project involves multiple tradeoffs and many decisions inviting engineering judgment.

At the conclusion of the project the true DO concentration is measured for each lake. The class compares the different group predictions to the ground truth measurement for each lake, providing insights into the realistic precision of data collection. The class observes the range of depletion and reaeration conditions pertaining at the six different lakes. Finally, the class sees and discusses the diverse engineering challenges addressed by other groups within the class. The final written report submitted by each group presents and examines the choices made in their particular design, but also documents the observations and conclusions they might offer from their overview of the attempts reported by the other groups over the range of six different lake conditions.

Past projects addressed other topics related to environmental engineering. An earlier version of the DO reaeration project used data obtained by telemetry from natural lakes of interest. Another project involved jar tests of two different treatment chemicals to clarify a volume of water containing a high concentration of solids, from which the group would design the dosage and time duration (with a limit of 10 minutes) of a treatment process to be tested against those chosen by the other groups. One past project involved disassembling small kitchen appliances to determine their material composition for recycling and for assessment of life-cycle environmental impact. Another project involved laboratory measurement of fluid flow from a tank, theoretically governed by the falling head equation, to design the outlet geometry to deliver a specific volume within a particular time limit. One more project involved data collection of traffic queues at signalized intersections, from which the group was to propose changes in signal settings to minimize environmental impacts; the proposals from the different groups were then compared in simulation software that illustrated the shifts in delays and costs, and thereby scored the different designs. It is invariably instructive and stimulating for students to see and discuss the tradeoffs that appear in alternate designs made by the other groups.

CONSTRUCTION PLANNING

A long-standing project involves planning, scheduling, and constructing a block wall, for which the unit costs and constraints force interesting tradeoffs and demand good decision-making. The task requires at least one trucker, who on each trip brings a load of blocks from one of two suppliers to the laydown area, and at least one mason, who transfers the blocks to the jobsite and lays them in the wall. The wall requires 96 blocks, and the load limit for a trucker (supply) cycle or a mason cycle is typically 4, 6, or 8 blocks, creating a project with roughly 16 trucker cycles and 16 mason cycles. The two suppliers are at different distances from the laydown area, with different unit costs, different load limits, and different headway intervals; truckers and masons have different labor costs, and (as in the real world) there is a storage limit at the laydown area. The typical time for a trucker cycle or mason cycle will be between 30 and 60 seconds, and the project duration is typically limited to 12 minutes. The group must decide how to staff the effort and how to schedule the job tasks, which can only be done after determining the cycle times for each of the labor categories.

Although the cost of any particular task is calculated by simple algebra, the many constraints between tasks make it difficult to extract an optimum. The student groups are instructed to narrow down the possible choices using their judgment and preliminary analyses, and then to schedule (and cost-out) a group of alternatives before choosing one for execution. Lectures and exercises introduce the standard production rate calculation, deterministic queuing, load balancing, Gantt charting, CPM, and resource leveling, including the use of software such as Microsoft Project for planning and scheduling.

Three different sets of unit costs are posed. One scenario corresponds to a rural location with no laydown limit but with long travel distances to the supply sites, another corresponds to an inner city location with minimal storage at the laydown area and with high labor costs, and so on. In a typical class with 15 groups, each scenario will be addressed by five groups. This project involves multiple tradeoffs and many decisions inviting engineering judgment. At the conclusion of the project the different plans for each scenario are examined, often showing a range of solutions that might be comparable in merit. The class sees the diverse engineering challenges addressed by other groups within the class, because the different unit costs in each scenario typically demand very different solutions.

STRUCTURES

The structures project presently used in the first-year course features the design, construction, and testing of a “popsicle stick” truss. Lectures introduce vector mechanics and force equilibrium, from which reactions on structures are calculated and from which bar forces in a truss are calculated by the method of joints. Other lectures introduce internal bending moment and the concept of bending stress in a rectangular cross-section, from which a failure stress is calculated when a plank or a popsicle stick is tested in bending. Other lectures and exercises introduce the normally distributed random variable and its use in engineering problems.

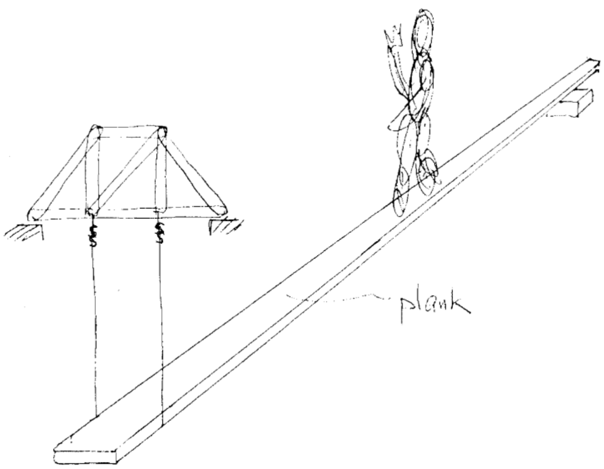

FIGURE 1. LOADING GEOMETRY OF TRUSS PROJECT

A test fixture sandwiches the truss between two plexiglass sheets, constraining the problem to 2-D and restraining compression members so that the onset of buckling does not produce overall failure. Connections between bars are made with small glued gusset plates, generally preventing connection failure. (Concepts of buckling and connection behavior are not treated in this course.) As sketched in Figure 1, the truss supports one end of a plank, and the truss is loaded as the instructor walks along that plank.

The group is required to design and build a truss with a failure probability no greater than 5% when the instructor walks the full length of the plank. The group tests six bar specimens in bending, from which they extract a sample mean and a sample deviation, and they perform the failure probability calculation for the most heavily loaded member in their truss. This portion of the project is graded on the correct calculation of member forces and probabilities, in the equivalent of a homework exercise, and not on the physical performance of the truss. However, the hands-on experience of testing the bar specimens to extract failure stresses, and the hands-on experience of building and testing the truss structure, provide visible and tactile reinforcement of the engineering concepts that were introduced. Careful observation of the failures is also an illuminating part of the student educational experience.

The truss design involves a number of tradeoffs created by fabrication constraints that interact with structural performance conditions. The truss must span 21”, but the basic bar is only 4½” long. These dimensional constraints would require a truss to have at least five panels (segments) along its lower chord, and would limit the truss height to something less than 4” because of the diagonal trigonometry. The group will not know if that last structural condition limits their design until they analyze a truss in that geometry and perform their probability calculations. (If their basic truss does not satisfy the strength requirement, they can specify doubling the overloaded members to achieve compliance.)

However, the group has a major design alternative that they may consider. At considerable additional cost, they can fabricate built-up bars with lengths as great as 9”. Such built-up bars would permit the construction of a much simpler truss topology, with only three panels along the lower chord, thereby reducing the number of joints, and with much greater truss height, thereby reducing forces in the chords. Do those advantages outweigh the additional costs? This question exemplifies the engineering decisions introduced in these projects. As in the other projects, the class sees and discusses the solutions chosen by the other groups, gaining further insight into the tradeoffs that characterize most engineering decisions.

Past projects addressed different structures topics. One project provided the group with 1x3 wood boards, to be tested to failure in bending, and then required the group to build a beam from those boards (perhaps I-shaped, perhaps box-shaped) that would be sufficiently strong to carry the weight of a Volkswagen Beetle; that project required lectures introducing moment of inertia and section modulus, and required a laboratory testing machine to evaluate the submitted beams. Another project provided the group with one sheet of cardboard and limited quantities of other supplies (package sealing tape, hot glue sticks, and white glue) from which they were to build a structure that would span 48” and support the weight of the instructor; that project was accompanied by a more conventional component in which the group was provided with a 1x3 plank and was required to calculate the failure probability when the instructor reached the middle of the 48” span.

ASSESSMENT OF STUDENT EXPERIENCE; CONCLUSIONS

Assessment activities performed for ABET accreditation purposes document effectiveness in student outcomes. Student comments and survey responses indicate satisfaction with the course and with the project activities. In anecdotal examples, individual students convey exceptional enthusiasm for the projects, although those students would be self-selecting and a controlled survey has not been performed. As noted earlier, undergraduate assistants are engaged to help run the projects, which provides a continued sense of community within the department and which provides multi-year feedback regarding the projects and changes that have been introduced to them.

Instructors are enthusiastic for the projects, which provide good examples for the material being taught and which appear to motivate the students. It is noteworthy that the projects evolve as collective efforts by different instructors who teach the course in successive semesters and years. The instructors view the student group experiences and the demands for technical communications to be significant contributions to the student educational experience.

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AUTHOR INFORMATION

Lawrence G. Cartwright teaches undergraduate courses in mechanics, materials, and capstone design. He contributed to the development of most of the first-year projects and is part of the team that updates and improves the project activities each year.

David A. Dzombak teaches undergraduate and graduate courses in environmental engineering. He taught the first-year course for five years, and developed projects related to structures, hydraulics, and water quality engineering.

James H. Garrett, Jr., teaches undergraduate and graduate courses in computer-aided engineering and engineering management. He was a co-developer of the first-year course, and its original hands-on projects, in the 1990s, and team-taught the course several times in the past few years.

Chris T. Hendrickson presently teaches courses in green design and sustainability, and formerly taught courses in transportation and construction management. He taught the first-year course on multiple occasions in the last five years, and introduced new projects relating to transportation engineering and sustainability.

Irving J. Oppenheim teaches undergraduate courses in mechanics and structures, and typically teaches the first-year course one semester each year. He introduced new projects in structures and in fluid mechanics, and updated other projects developed by his colleagues.

James M. Thompson teaches undergraduate courses in mechanics and structures, and will team-teach the first-year course for the first time in Fall 2012.

Jeanne M. VanBriesen teaches undergraduate and graduate courses in environmental engineering, and presently teaches the first-year course one semester each year. She introduced a new project using real data from environmental sensors.