Our Experience with Guiding a Major Design Experience in Civil Engineering Curriculum

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Abstract

The authors have been involved in developing and offering a course for seniors in Civil Engineering at Portland State University for the past fifteen years. The course (Civil Engineering Design) began as an experimental course taken by students as an elective, but soon became a required course for all seniors. It is taught during the spring quarter of the senior year as a "capstone" course and constitutes the last required design course in the program. A course entitled "Engineering Project Management" is a precursor. The goals of the design course are to make it as near to actual design office practice as possible, for the instructors to "guide" the students as opposed to "lecture" them, and to have practitioners guide the design projects.

Introduction

Portland State University (PSU) runs on a quarter system, with each quarter spanning ten weeks plus final exams. Civil Engineering curriculum at PSU includes two years of math, one year of chemistry, and one year of physics, in addition to the usual engineering mechanics courses and freshman problem solving and graphics. At the sophomore level, a course in surveying, one in properties of materials, and one in electrical circuits are required.

Starting at the junior year and continuing through the second quarter of the senior year, the required engineering courses include: one course in thermodynamics; three courses in fluids, hydraulics, and water resource systems; one course in environmental; one in engineering geology; two in geotechnical; two in transportation; three in structural analysis and design; and one course in project management.

By the time the students reach the capstone design course (CE 494) which is offered in the spring quarter of the senior year, they have already acquired the necessary knowledge and tools for basic analysis and design problems in structures, transportation, geotechnical, water resources, and environmental engineering. A single course in engineering project management (CE 484) is required in the fall quarter of the senior year, and twenty credits of technical electives taken in the senior year round out the knowledge for emphasis in one or two of five specialization areas.

The course in Engineering Project Management lays an essential foundation for the capstone design course. So in a sense, we have a "sequence" of two courses that involve thinking at a "system" or "project" level. Because of the special importance attached to the project management course, we see fit to give a summary description of this course below, before giving a detailed description of the capstone design course.

I. CE 484 Engineering Project Management

The course introduces subjects used in the management of engineering projects. The catalog course description currently is: "Engineering processes including owner-design professional-constructor relationships, procurement procedures, project evolution; contracts, dispute resolution, bonds, warranties; construction documents, including specifications; cost estimating, planning, and scheduling; construction administration; group process, diversity and leadership. Prerequisite: senior standing in Civil Engineering."

The textbook used, "Engineering Project Management," is by E.S. Huff, and is a set of bound notes prepared as a textbook. The goals of this course are for students to learn the fundamentals of engineering project management and to utilize that knowledge and design knowledge gained in other classes in a project involving research, written reports, and oral presentations by teams.

The topical outline of this course is as follows:

> The engineering process, including the players - owner, design professional, constructor; the procurement of services - design professional vs. constructor; public vs. private; and project phases - study and report, design, bidding, construction, operation.
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> Legal issues, including contract fundamentals; contract particulars dealing with engineering and construction; and special issues such as bonds, insurance, warranties, and financial incentives.
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> Construction documents including graphic and written documents; bidding information, contract documents including specifications, drawings, addenda, and modifications; CSI format; specifying methods including prescriptive vs. performance and types of prescriptive specifications - descriptive, reference, proprietary.
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> Cost estimating including AACE accuracy ranges; bidding strategies; quantity and productivity estimating; standard resources such as cost estimating manuals, in-house records, on-line sources, and consulting services; and value engineering.
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> Planning and scheduling including critical path method, time scale arrow diagramming, economy studies, schedule crunching, resource leveling, and the use of scheduling software.

Construction administration including responsibilities of the owner, design professional, constructor, and construction manager during the bidding and construction phases.

Group process and leadership including group formation; decision making; conflict resolution; and dysfunctional phenomena in groups.

Term project including research focusing on the administration and management of a completed or on-going design or construction project planning and scheduling; cost estimating; submission of individual and group written report; group oral presentations; and peer review.

This course is a precursor to the Civil Engineering Design course. For example, students learn about budgets, feasibility studies, cost estimating, and construction specifications in CE 484, and then apply them to their capstone project in CE 494.

III. CE 494 Civil Engineering Design

At the outset of "designing" this capstone course, our goal was to make the course as realistic and as near to actual design office practice as possible. Our second goal was to "guide" the students, as opposed to "lecture" them, even though distinguishing between the two becomes blurred at times. Our third goal was to have practitioners guide the design projects. Each team of about a dozen students works on a design project that involves several, but not necessarily all, of the civil engineering specialty areas. These areas have normally included structural, geotechnical, water resources, and environmental engineering, with a strong component of project management, construction, and socio-economic factors. Projects offered to the teams are real projects, extracted either from those with which the practitioners have been heavily involved in recent years, or from on-going projects at the time the course is offered.

The current catalog course description is: "Synthesis of civil engineering specialties in a diverse multi-disciplinary project. Teamwork approach in design of components and systems to meet stated objectives. Consideration of alternative solutions, methods, and products including constraints such as economic factors, safety, reliability, and ethics. Preparation of design documents, including: memoranda, computations, drawings, cost estimates, specifications, bidding materials; written and oral presentations. Two lectures, one 3-hour design project laboratory period. Prerequisite: senior standing in Civil Engineering."

The goals for this course are: Synthesis of CE specialties in a capstone course, providing a meaningful major engineering design experience including economic factors, safety, and reliability; development of interpersonal skills and understanding of work team dynamics.

Practicing professionals from the engineering community act as mentors for the discipline groups, to help students learn the requirements of design practice within each discipline. The design process includes open-ended problems, formulation of design problem statements and specifications, feasibility considerations, alternative solutions, concurrent design, and preparation of detailed drawings.

The prerequisites by topic are: Basic knowledge of structural, geotechnical, transportation, environmental, and hydraulic engineering; basic elements of cost estimation, scheduling, and engineering economy.

The topics (2 hour classes) for the “lecture” portion are varied depending on the instructors, but generally have included guest speakers on topics including:

1. Personality Types and Diversity in Project Teams, Myers-Briggs Testing
2. Values Based Decision Making
3. Selecting Engineers and Value of Engineering Services
4. Engineering Ethics and Engineers in the Community
5. Strategic Planning
6. Guest Lectures from Engineering Professionals
7. Contract Bidding and Construction, Alternative Project Delivery Methods

The topics (3-hour sessions) for the “lab” portion are varied, depending on the instructors and the design projects selected by the students, but generally have included the following:

1. Project Approach/Project Instructions
2. Project Siting
3. Conceptual Design
4. Interdisciplinary Project Management & Scheduling
5. Contract Document Development
6. Cost Estimating
7. Construction Scheduling and Constructability

A key requirement of the course is for the students to work in preassigned project teams. The teams are assigned in a manner that provides a diverse group based on engineering major and background. This group must work together to develop the project, understanding and utilizing each team member’s strengths and weaknesses. Each team is also required to make two formal oral presentations to the class. One of the presentations is an interview for the project, which is evaluated by the class using a weighted evaluation matrix. The second presentation is a formal presentation of the final project. Each group is strongly encouraged to utilize graphics to the greatest extent possible, and each team member must make a portion of each presentation.

Some instructors assign a project manager to each group and meet with the group every week. Other instructors allow the groups themselves to assign the project management position to one of their group members.

The projects that the students take on are real projects, usually coming from those with which the practitioners have been heavily involved in recent years. Two examples of recent projects are given below.

Project: Bull Run Lake Dike Spillway and Access Road Reconstruction
Owner: City of Portland Water Bureau

Bull Run Lake is an earth embankment structure 25 feet high, and 500 feet in length with a crest width of 15 feet. In 1932 the dike was breached by high water and was not repaired until 1957. In 1987, the dike was reconstructed and raised to its present elevation of 3184 feet. The embankment has continuously undergone erosion due to wave action generated by high wind velocities when the lake water gets high during spring thaw. To avoid any potential breaching of the dike, the Bureau decided to redesign and reconstruct the dike. The main components of this project were Dike reconstruction, Spillway reconstruction, and Access road reconstruction. Geotechinal engineering, hydraulic and water resources engineering, structural engineering, transportation engineering and environmental impact assessment were the main technical elements of this project. Alternative solutions and criteria development for cost, construction (environmentally protected zones) and limitation in access, short window of construction, limitation of non-native construction materials were among the main challenges of this project to arriving at the best alternative solution. Students were mentored and guided through all these steps.

Project: Bowman Bridge Roadway and Pipeline Bridge and Seismic Strengthening
Owner: City of Portland Water Bureau

Bowman Bridge is an existing steel truss bridge built in circa 1890. This bridge carries two water conduits which normally supply two thirds of the City of Portland water from the Bull Run Watershed. It has a total span of 330 feet and is supported by two bents consisting of two 5-feet diameter steel pipes per bent on each side of the river. This bridge was originally designed for a seismic peak ground acceleration (PGA) 0.10g. Since Oregon and Washington seismic zone rating were upgraded to a higher demand level, it was decided to upgrade this bridge to withstand a PGA of 0.29 to reduce its vulnerability to seismic loading. Earthquake, structural, geotechnical, water resources and hydraulic engineering and environmental impact assessment (permitting) were the main components of the project. Alternative solutions and criteria development for cost, construction (environmentally protected zones) and limitation in access, short window of construction, limitation of non-native construction material were among the main challenges of this project.

During the course of these projects, students were mentored and guided with the focus on:

1. Development of alternative solutions (Matrix)
2. Development of Criteria for best solutions (technical, cost, environmental, constructability, etc.)

3. Application of criteria
4. Refining the alternatives
5. Selecting the best solution
6. Designing the system
7. Finalizing cost
8. Development of construction schedule
9. Team work
10. Preparation and presentation of report

Guest lecturers have often been invited to the lecture session to discuss the importance of multidisciplinary approach in successful implementation of civil engineering projects. Students become aware that there is no best design or best project. Instead, there is a "balanced design" or "balanced project" in which a project has been selected from a range of alternatives, and each alternative has been filtered for technical and economic feasibility, cost effectiveness, and environmental acceptance. The guest lectures emphasize the art and science of synthesizing these factors in making a successful civil engineering project.

Course evaluation is done in two ways. One is through a questionnaire that the department utilizes for all courses. This evaluation deals with the overall effectiveness of the course delivery, textbook, etc., and students are encouraged to provide additional critique for the course. A second evaluation is through a peer review process done for each team, by other teams. These evaluations deal with thoroughness of the project design and presentations.

IV. Observations

It has been interesting to observe the students adapt to performing in the project environment. In this course, the students find that there is no “right” answer to the problem. The actual answer is based on the values with which the individual group members use in their decision making at various decision points in the design project. Many of the students adapt well to this, but some find if very difficult to grasp this concept.

Our experience with this course has been rewarding. We continue to experiment with different modes of guiding the student projects. Some instructors tend to set the overall guidelines of the projects, and leave most of the decisions to the students. In such cases, the student groups at the time of project review and presentations attempt to justify their decisions. Other instructors tend to be more mentor-like in their approach. They guide and supervise the group activities, participate in debates, and lead the students to more prudent designs. Which method is more effective depends, to a large extent, on the instructors’ viewpoints. Of course, judgement must be exercised as the instructor deals with different student groups and individual students. The course has been changing and evolving as we continue to experiment with different ideas to make the course a more meaningful major design experience.

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