A Comprehensive Engineering Student Experience through the Senior Design Course

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Abstract

The stated purpose by law[1] of the South Carolina State Board of Registration for Professional Engineers and Surveyors, as similarly required in other states, is to protect the health, safety, and welfare of the public by ensuring that only properly qualified and competent engineers are licensed to practice through the promotion of technical competency and ethical standards. Furthermore, engineering companies have a need for employees and highly regard new graduates that possess business related skills and qualities. These are weighty and often difficult matters for individuals transitioning from student to professional life. The University of South Carolina's (USC) Capstone Senior Design (Senior Design) course in the Department of Civil and Environmental Engineering is structured to provide a practical experience to give students a glimpse into the life of daily conduct of engineering practice beyond just the performance of design calculations. This article details the Senior Design format at USC and highlights the comprehensive nature of the course and the significant industry cooperation it fosters.

Keywords

Senior Design, Competence, Ethics, Mentoring, Professional Experience

Introduction

A capstone design project is a common civil engineering student experience. Most programs typically focus significant attention on the planning, analysis, and design of a project that includes the major disciplines of civil engineering (environmental, geotechnical, hydrology/hydraulics, structures, and transportation) and culminate in a set of drawings, a report and a presentation. Coupled with interaction with practicing professionals, the experience provides an idea of work life beyond the classroom, but it can fall short on answering important questions that students need to know:

- What does it mean to protect the health, safety and welfare of the public?
- What is required of me to be technically competent?
- What ethical standards are required of me?
- What skills and qualities do I need to get hired?

A number of resources are available that provide industry hiring objectives and employment issues. These resources, such as Dan Schawbel's book Promote Yourself: The New Rules for Career Success[2] and others, provide interesting glimpses into employer perspectives of new college graduates as employee candidates and how they stack up to employers needs. The following table provides a sampling of companies' desired "soft" skills and qualities of good

candidates compared against skills lacking in college graduates. A clear disconnect has obviously existed between employer needs and student preparation.

Most Desired Skills and Personal Qualities	Top Skills Lacking in College Graduates
Communication	Communication
Interpersonal	Relational
Initiative	Self-confidence
Analytical	Initiative
Problem-solving	Organizational
Teamwork	Teamwork
Work Ethic	Work Ethic
Flexibility	Flexibility

These indicators have similarly been noted historically by local South Carolina firms who further note a lack of time management skills, maturity, professionalism and understanding of business etiquette and dress for a professional environment. Senior Design at USC has evolved over the years to better provide a comprehensive student experience specifically focused on developing skills that align with the top priorities of industry for technical skills, professional conduct, and personal attributes.

Senior Design Overview

All seniors in Civil Engineering at USC are required to take the 4 credit hour capstone design course, ECIV 470 - Civil Engineering Design. Senior Design is an essential component of USC's Civil Engineering curriculum. It provides students an opportunity to apply the principles they have learned in the classroom in a controlled environment, moving from the pure theoretical of the classroom to a real project design with schedules, budgets, issues, and construction. The objective of Senior Design is for student teams to work together on, and design, real-world, interdisciplinary projects that local engineering practitioners (and partners with USC) have completed, or are currently developing, and have made information available for the class. The students' design must be constructible, but shall not replicate what was designed professionally. The over-arching objectives for the class are:

- Involve each student in a total project experience
- Emphasize teamwork and organization
- Mentoring by Professional Engineers
    - Ethics, professionalism, management, and leadership
- Exposure to codes, guidelines, and regulatory permits
- Introduction to engineering design drawings, specifications, and other construction contract documents
- Exposure to budget, cost estimations, and schedules
- Involves the student in an evaluation of alternatives
- Oral and written communication

Depending on the number of students, the class is divided into design teams of 5 to 7 students. Each team has its own unique project or component of a larger, comprehensive project. Each

project shadows a real world project that is ongoing, recently completed, or planned. The students work under the guidance of a project sponsor and professional mentors, who are registered professional engineers working with local civil engineering design companies.

The list of sponsors and mentors has grown over many years of work with local practicing professionals who have a strong interest in the success of USC's program and often have gone through Senior Design at USC themselves. This enables "hand-picking" the right sponsors and mentor teams to fit the skills and practice focus of the students. The project sponsor is typically the engineer-of-record for a project who engages with the students on the actual project, often with the ability to provide access to the physical project site, plans and specifications, calculations, and face time with clients, permitting agencies, and other consultants. This close coordination with the sponsor, together with the project client, enables the students a real, tangible problem to work on and helps to provide broader access to project information without intellectual property concerns.

Project plans, reports, specifications and other documents are typically made available, but it is not the intent of Senior Design to replicate these designs or produce a full set of engineering documents for construction. The students are challenged to ultimately display an understanding of the general design of the whole project specifically focused on overall coherence, effective coordination between design components, appropriate cost, and feasibility of the design. They are also encouraged to innovate and come up with new (and maybe even better) ideas.

The students are also encouraged to network with and establish working relationships with their mentors. These mentors are recruited by the instructor to be available to provide support as needed. Specific training needs are typically discussed beforehand so that the mentor is focused on not only providing technical support but also practical support on business practice. The students meet with their mentors on a regular basis, typically at the office of the mentor.

Prerequisite Courses

Senior Design assigns multi-disciplined projects such as design of a dam, a regional wastewater treatment plant, a subdivision, or a bridge. The students must define the problem, generate a range of solutions, evaluate each one using engineering criteria, and develop the final solution in detail using the analytic techniques learned in civil engineering courses. Since civil engineering students generally focus their energies on the technical aspects of their own disciplines of study, the work on their individual parts of the project are understood through the technical prerequisite courses. But the Senior Design course pushes students into often new territory such as working in a team environment, setting their schedule, deciding which of the many resources and tools available are appropriate, accomplishing a design that could actually be physically built in a complex system, coordinating with mentors in a professional manner, and presenting ideas in written, graphic, and oral form in as professional and convincing manner as possible.

Therefore, the students must learn new "soft" skills of engineering practice. To accomplish this, students are engaged with a prerequisite course that is complemented with the interaction with the practice professional mentors. There is a prerequisite course that is critical: ECIV 405 - Systems Applications in Civil Engineering. ECIV 405 is a 3 credit hour course that provides Project Management fundamentals including a systems approach to analysis and design;

application of engineering economic principles to the evaluation of design alternatives; deterministic modeling; and optimization emphasizing civil engineering applications. This course offers class instruction on these subjects and guest lectures from practicing professionals who are engaged in managing various types of civil engineering design and construction.

Professional Mentors

To help the teams understand the broad spectrum of issues in industry practice and to solve specific problems on the their Senior Design projects, the students attend lectures given by, and meet individually with, local professional mentors on a variety of topics including design and code compliance, legal issues, business etiquette, marketing, presentation skills, ethics, quality control, scheduling, cost estimation, plan preparation, contracts, and technical writing. Interaction with practicing professionals is required, exposing the students to the office environment and permitting the opportunity to use newly learned business skills. The following summarizes key issues that are often covered by the mentor over the course of a semester with the students:

Licensure Questions

- P.E. and C.O.A. Responsibilities
- Protection of the Public
- Competency for Assignments
- Conflicts of Interest
- Protecting the Interest of the Client and Company
- Honesty and Integrity in Practice

Skills

- Help to understand overall understanding of project components
- Assist with design, software, etc.
- Business etiquette
  - Attire when meeting with mentors, clients, etc.
  - Interaction: shaking hands, vernacular
- Technical writing
  - Proposals, letters, reports
- Leadership
- Business finance
  - Cost or revenue accounting
  - Cost-plus fixed fee or lump sum agreements
  - Proposals
- Effective Communication
- Human resource issues
  - Legal requirements
  - Staff support, behaviors, etc.
- Presentations
  - Perform Mock Jury Panels

- Legal issues

Management of Their Project

- Scope Management
  - Understanding client requirements and expectations
  - Accepted by the client
- Schedule Management
  - Project completed on time
- Issue Management
  - How to recover when things go wrong (which they will)
- Cost Management
  - Project meets clients budget and scope
- Quality Management
  - How to make sure plans, report, and presentation are top-notch

Class Mechanics

The course instructor selects the composition of each design team with input from the class. Factors in deciding team members include balancing student talents and interests. The team must learn how to work cooperatively and effectively with others. Each team must understand the individuals on the team to focus talents and interests of each person in a complementary and consistent way to meet project objectives. Historically the groups that have finished on time, and with the best projects, have been those that met regularly outside of class time, cooperated, and shared project responsibilities equally. To replicate this, the teams are encouraged to meet regularly and communicate, and the instructor counsels them on the best ways to accomplish this. Regular communication has shown to be supportive to exchanging ideas and exploring new concepts, project planning, monitoring each person's timely and responsible contribution, and, obtaining feedback from team members that influences the final design.

The class is required to meet regularly during the semester in a classroom setting where they can work on their project and get advice from the instructor. Over the course of the semester each student makes an individual presentation during this class on some aspect of her or his design team project. The instructor provides a general list of potential topics. Each student's presentation is peer evaluated using an evaluation form developed by the instructor, which becomes part of the students' final grade determination.

The following paragraphs are taken from the Senior Design Handbook. They provide a sampling of the insights given to the students and the underlying focus on critical skill development. The tenor is direct dialogue with the student, hence frequent reference to 'you.'

> ***Get started ASAP****. The first suggestion for successful completion of your project is to start as soon as possible. Once your team and project are known, hold your first team meeting to discuss division of effort. There are a number of tasks that you should accomplish in the first week after you begin your project. These include obtaining any permits that may be required and making initial contacts with resource personnel.*

Define the problem. *Defining the problem is almost always one of the most demanding (and often frustrating) steps in any project. It's tempting to say, "We're going to design a new" and start making sketches. That's a mistake! What you're asked to do is analyze the situation that led to the request for design. What needs must be met by the completed project? How are they measured? Looking at a problem this way often leads to the expected design solution. However, there are times when a clear definition of the needs leads to an unexpected solution. Heed these words! Don't become overly ambitious! You only have 12 weeks to perform the design and complete the first draft of your engineering report. One of the most common problems is to define the project scope too large or complex, particularly in light of the time limitation. Evaluate the success of the design--in quantifiable terms. For most civil engineering projects, there can be literally hundreds of parameters that must be within pre-defined values. It is up to you to define them and rank their priority so you may choose among alternatives during the design process.*

Define the work product. *Look ahead to what you're actually going to present at the end of the semester. Be as specific as possible about the elements of your report, the analyses you're going to perform, the drawings you'll make, and how you're going to show them. If you examine the final product early, you'll almost certainly see weaknesses that need to be addressed as well as uneven detail.*

Read previous project reports. *The course instructor has project reports from prior years. Review them early to see what is typical of the level of work required and the various ways it can be presented. Don't feel that you must copy these projects--every one could be improved significantly. Nevertheless, these reports serve as a good starting point.*

Develop a project schedule. *One of the most recommended and least followed aspects of Senior Design is to develop a Critical Path Schedule for your project. It's difficult because you haven't been through the entire process yet so it's almost impossible to anticipate all the steps, and even more difficult to estimate how much time each will take.*

Perform all research. *You should complete all data gathering during the first 4-6 weeks, leaving the remainder of the semester to developing your design and performing the necessary analyses. Types of data that you may need to assemble include:*

Codes. *What are the relevant codes for your project? Examples are Zoning, Building, Fire, Health, Handicapped, Historic, Life Safety, etc. What are the key sections within each of those codes for your project? Are there any conflicts among them? If so, how are you going to resolve those conflicts? You'll probably need to visit the city, county, or state offices to learn much of this information. Be warned that making an appointment mutually convenient to everyone can take several days. Don't wait too long.*

Permits. *Any project involving construction activities will require one or more permits. Examples include stormwater and erosion control permits from DHEC (or county engineer's office), 404 wetlands permit, etc. You must obtain a copy of the permit application for any and all applicable permits and address the requirements of each permit as part of your design.*

Site Characteristics. *Each team must accomplish a design that could be built at a given location; therefore, it is imperative you determine and document the existing site conditions. This process rarely goes smoothly. Start early, work hard, and be prepared to explore alternatives. What are the characteristics of your site? Topography, stormwater drainage, utilities, rights of way, earthquake zone, wind load, environmental pollutants, view requirements, traffic access, etc., are examples of issues to be considered.*

Soils. *What are the soil conditions? You must obtain relevant soils information for your project. If soil boring information is available for your project site and can be shared, the course instructor will arrange for this information to be given to your team. Not all projects, however, will have soil boring information available. It may be necessary to extrapolate from nearby borings, or perhaps from soil maps or conversations with local engineers. Appropriate sources of information can take a long time to pin down.*

Alternatives. *To meet the project needs, your design team should consider a number of alternatives. What are the properties of the alternatives? How do they interact with other systems? How can they be measured by the criteria you've established? Often this stage of the project will require conversation with people at regulatory agencies and public works departments, and with manufacturer's representatives and local engineers. The time involved can be considerable.*

Materials. *What materials are appropriate to your project? What are their properties, cost, longevity, workability, etc?*

Develop design alternatives to consider. *You'll undoubtedly consider design solutions as you work on the many details necessary to define the problem. That's good, but don't let them become fixed too early. Once you have the major problem well defined, take some time (a brainstorming session is very useful) to develop the basic alternatives you're going to explore. They must be elaborated enough to allow understanding of all major system components, but not so elaborate that you're unwilling to toss one aside for another, or to combine the best aspects of different ideas. Costs should be considered for the alternatives as well.*

Expanding the class into new territory for the most recent Senior Design class, each team, prior to designing their project, was required to submit business proposals to the Project Sponsor who served as the Client. The intent of this exercise was to provide experience with technical writing, marketing, legal issues, and financial data. Committees (professors, practitioners, etc.) critique these documents and provided feedback to the instructor. To complete their projects, students must apply engineering design principles; successfully work in their teams overcoming the challenges of group personalities, schedules and deadlines, and internal and external communications; and use skills learned through practice professionals.

The work of the teams is expected to be presented in a very organized, condensed manner, and they are encouraged to be aware of the submittal requirements and plan for them throughout the semester. In one semester, each team goes from learning their project to a set of three

deliverables. The deliverables include a reasonable set of design drawings, an engineering report with cost estimate, and an oral presentation and defense of their design to a Jury Panel.

The engineering drawings are to be sufficient to clearly illustrate the overall design. Due to time limits, the students are not expected to develop detailed drawings for each component of the design. Failure to provide an acceptable set of drawings will result in the loss of one letter grade on the final grade for each member of the team.

The engineering report is a document presented to technically literate readers, explaining in both summary and detail the nature of the team's project, goals, what was attempted, how the team performed the technical analyses, results, and conclusions about results. The document is written as would a report for submittal to the permit agencies. Reports from previous classes are made available and the teams are strongly encouraged to review these.

The Jury Panel and Grades

The professional Jury Panel is comprised of two or three faculty, two or more design professionals, and one or two people from permit review agencies. The panel members review the reports, plans, and participate in the "jury" review of the team presentations. During the team Jury Panel, each student delivers part of the team presentation. The team is asked questions and challenged by the Jury Panel Jury Panel on design specifics, quality, challenges faced, and other areas of interest to the Panel. These discussions generally lasts for two or more hours. Each student is asked multiple questions about her or his part of the design and about other aspects of the design, and must demonstrate general understanding of the overall project and how the various elements interrelate within the overall design.

Student grades are based 30% on individual scoring and 70% for team scoring. The team is scored by the Jury Panel on quality of presentation, drawings and engineering report. Individual scoring includes Peer Evaluation of individual presentation, Jury Panel Evaluation of individual presentation during team presentation, Peer Evaluation of overall performance, and instructor scoring of student's overall performance.

Project Examples

There are cases in which there are multiple projects available from the engineering community that permit individual teams to be assigned a particular project. At other times one large general project provides an excellent opportunity to enhance the learning experience. One such project was the relocation of Cardinal Newman School in Columbia, SC, which was a project in

planning. This project was unique in the following ways. The class functioned as a Company with four departments: General Site, Transportation, Building, and Athletic Facilities. At the start of the semester, the class went to Cardinal Newman and met with the principal (Client). She talked with the class about what she wanted from the design. The students prepared monthly progress reports throughout the semester that were delivered to the client. During the last week of the semester, the class again went to Cardinal Newman and presented their design to the client and others. A group of five made this presentation. It is worthy to note their class design had to deal with real world budget constraints in terms of how much Cardinal Newman expected to have available to pay for the relocation. Also, the proposed site has major topographic, wetlands, traffic and general environmental issues with which the class had to navigate. Overall, the students liked working on a common project instead of individual projects. The instructor was impressed there was greater class interaction and overall learning by the students.

Another general project was the renovation of the Old Farmers Market, across Bluff Road from the USC football stadium, to a football Saturday tailgate facility with facilities for other venues. The class was divided into transportation, general site, building and environmental design teams. The following semester brought the Athletic Village for the USC. Major components included two buildings, site layout and grading, athletic fields, bus access and parking, an underground stormwater storage facility that supplied water to the athletic fields spray irrigation systems, ADA compliant walkways, and Low Impact Development. Both of these projects were well received by the students and encouraged broad enhancement of personal skill development.

Conclusions

Senior Design at USC is focused on providing a comprehensive student experience. This is intentionally focused on developing skills that give students the best opportunity to succeed in the "real world" by ensuring that USC's top priorities align with industry for technical skills, professional conduct, and personal attributes. The following table is a summary of the critical skills and qualities important to an engineer's obligation under the laws governing practice and meeting industry needs, and how Senior Design supports those efforts.

Critical Skill/Quality	Senior Design
Protect Health, Safety and Welfare of the Public	Learn from mentors requirements of law, professional conduct, competency
Technically Sound	Must have defensible design and be able to demonstrate knowledge during Jury Panel.
Ethical Standards	Mentors help students understand Rules of Professional Conduct. Can't cut corners – Jury Panel will know and expose issues
Communication	Must communicate well with team members, instructor, mentors, clients, and Jury Panel. Presentation and report writing required.
Interpersonal	Critical to successful completion of project. Mentors provide great support to help dealing with personalities.
Initiative	Required to get out of comfort zone and work with mentors, permitting agencies, etc.
Analytical	Must produce calculations and have defensible design.
Problem-solving	Required to come up with new ideas and not replicate project. Must deal with legal, permitting, utilities, and other constraints on their project.
Teamwork	Must be unified to meet schedule, presentation requires team effort
Work Ethic	Very tight schedule with specific required deliverables. Must work hard to make the grade.
Flexibility	Tight schedule, must work within confines of other classes, mentor and others' availability, project issues and constraints

The success of USC's Senior Design course towards meeting these objectives has been demonstrated in numerous ways, but most notable by: the dependable and extensive industry support provided, student feedback, professional mentor feedback, and industry feedback regarding the talent of the students coming into practice. The annual success of the Senior Design course is directly related to the extensive support provided by South Carolina's engineering firms and individuals, many of whom went through the course as well. There is never a shortage of project sponsors, mentors, or jury panelists. This is truly a testimony to the format and success of the program.

Students in the program are regularly polled to assess the program and make continuous improvements. The following quotes represent feedback consistently received about Senior Design:

> Regarding the strengths of the class: *"Teaches real world design concepts and forces students to interact with each other in a setting that more closely resembles the real world rather than a traditional academic setting."*
>
> Regarding Senior Design's preparation for life after graduation: *"Absolutely. Senior Design provided me experience to work through practical design, and become acquainted with how to work the "tools" we're taught throughout undergrad. The presentation portion of the class, I believe, is as equally valuable as the design portion. Presentation experience is extremely valuable, and being provided the opportunity to discuss technical topics with design and academic professionals is invaluable. Here you have the ability to "practice" the presentation skills that are need when interviewing for a client, potential employer, or giving a presentation to peers."*
>
> Regarding professional mentor support: *"I believe having current working professionals that deal with similar projects day in and day out, review and comment on deliverables was one of the greatest learning experiences in senior design. For engineering professionals to evaluate your work, tell you what you did right, what you did wrong, and why, was a great introduction into the real world."*

It is also important to hear from the practice professionals who support the program. During the class presentation to the Client for the previous described Old Farmers Market project, the lead engineer for the company that did the actual design for the Athletic Department was present and made the comment that he learned something from the class presentation and, as a consequence, his company would reconsider part of their design. This feedback served as validation of the effectiveness of the class structure and focus on innovation, and also provided significant encouragement to the students involved.

In conclusion, the University of South Carolina's Department of Civil and Environmental Engineering Senior Design course is focused on matching student skills with employers' needs. To accomplish this, the course is focused not only on technical skills but the "soft" skills that are critical in everyday practice. A large national engineering company began recruiting on campus for new graduates in recent years. A senior human resources director for the firm stated at this year's USC job fair: "We were pleasantly surprised by the broad based talent of the individuals that we met and subsequently hired. Not only were they technically sound, but that had intangibles – those soft skills that make for successful engineers in practice. We will definitely be back as the talent at USC is on par with the top engineering programs that we visit." We believe that the evolution of Senior Design toward meeting specific industry needs is a key to this success.

References

1 South Carolina Code of Laws, Title 40 – Professions and Occupations, Chapter 22, Engineers and Surveyors, 2013
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