Teaching Civil Engineering Design using Project-Oriented Industry Driven Capstone Course

Waddah Akili
Principal, Geotechnical Engineering, Ames, Iowa, USA
Email:w.akili@isunet.net

The paper sheds light on the development, implementation, and subsequent evaluation of a senior design course at an international university, where practitioners have played a major role in planning and teaching the capstone course. The new restructured design course, co-taught by practitioners in the locale, has met its declared objectives and exposed students to professional practice. This industry-driven experience has also provided information with regard to curricular content and capabilities of graduates. In a way, the capstone experience reported on here, serves as a microcosm of the four year program. Outputs from the course can be used to provide guidance and insights into curricular changes, teaching methods, and exposure to local practice; and helps in establishing connections with the industrial sector.

Introduction

Design is widely considered to be the central and the distinguishing activity of civil engineering. Historically, engineering curricula have been based largely on an "engineering science" model, referred to as the "Grinter Model" [1], in which engineering is taught only after a solid basis in science and mathematics. The resulting graduates perceived by industry and academia, at the time, as being "ill-prepared" for the practice. Despite steps taken to remedy the situation, through industry-academia collaboration; both, faculty and practitioners argue that further improvements are necessary.

This paper reports on the development and execution of a senior design course at an international university, where practitioners played a major role, side by side with faculty members, in planning and teaching the capstone design course. Development of the course plan coincided with a departmental decision to revamp and update the existing senior design course, to more effectively relate the concepts of design and to expose students to professional practice in the Region. The restructured course, co-taught by a local consulting firm, has met the objectives and, asserted that design is a series of interconnected and thoughtful processes that depend on: solid engineering background, generation of design concepts, and arrival at relevant specifications that make it possible to realize the design concepts [2, 3]. This industry-driven experience has provided valuable feedback on curriculum and capabilities of graduates.

Reporting on the Experience

Here, the author describes the restructured capstone design course, and reports on this experience under three headings. ***First***, sheds light on causal factors that lead to restructuring***. Second,*** reports on the restructured course. ***Third***, looks at outcomes, and examines the effect of restructuring the course on students, faculty, and potential modifications to the curriculum**.**

The Status Quo & Conditions that Triggered the Change: The main goal of the senior design course, at the International University, is to have senior-level students' work on group projects under the guidance of faculty members in their area of specialization (i.e., structures, transportation, environmental, etc.). Students were required to adhere to a specific format in meeting course requirements, including: adherence to a pre-set schedule, meeting with faculty member(s) on regular basis, submission of a mid-semester report and a final report, and an oral presentation at the end. Oral presentations are evaluated by all those in attendance. The course grade was based principally on reports' grades given by the faculty member(s) who guides the student through the course/project. i.e., less weight was given to presentation evaluations. The above format was problematic and not looked upon favourably by faculty and/or, students. The major concerns have included:

1. Great deal of variation in terms of efforts and time spent by the student, and demanded by the faculty during the entire course duration, i.e., some faculty were harder and more demanding than others.
2. Most students were apprehensive when their turn came to register for the senior design. They were mindful of working harder than usual, and not reaping the benefits that come with hard work.
3. Young inexperienced faculty members, who were more inclined towards analysis rather than design, were not prepared or sufficiently capable in providing the guidance required to fulfill the mission.

4. The amount of work required by faculty members in the capstone design course was well below the credit given to the instructor, and for most was outside their area of interest or scholarly activities.
5. Most of the design projects were made-up projects with hardly any connection or relevance to what goes on in the arena of local design practice.
6. Although students were supposed to be working in teams, many had problems attributable to little or no prior experience in team membership.

As can be noted from the discussion above, there were serious deficiencies that had to be corrected, to provide students with design knowledge and experience to meet the needs of industry. In addition, the course format was not addressing some of the basic underpinnings of a capstone design course (e.g., *compatible* design projects that depict local conditions, technical support of *practitioners*, effective *teamwork*). Also, alumni feedback indicated that the course did little to prepare students for professional practice. The consensus was to revamp the existing design course in favour of a new course designed to do away and/or reduce the pitfalls indicated earlier. Finally, the impetus for changing the format came from three groups: the faculty, senior students, and graduates who wanted to share their impressions based on their own experience as students in the design project. After several meetings, most have agreed on the major characteristics of the new capstone course and the way it ought to be restructured. The new format called for the following:

1. Industry involvement and/or real world problems should be used as the focal point of the course,
2. Delegate the primary responsibilities of advising, mentoring, etc. to practicing engineers, preferably those who have practiced in the Region.
3. The course should address relevant non-technical topics associated with engineering design such as: ethics, litigation, finance, social impact, etc.
4. Insist on teamwork and allow students to select their own team members, and
5. Final course grade to be based on a combination of: team performance and individual performance.

In order to define the new structure of the course, subsequent meetings were held between selected faculty members and administration personnel to ***either*** recruit the right type of faculty, ***or*** delegate the responsibility to a competent consulting firm in the vicinity, willing to undertake the mission and able to provide licensed professional engineers to assume the responsibility of: mentoring, guiding, advising, and leading the capstone design course. After an extensive search, the decision was made to delegate the task to a medium-sized multidisciplinary firm with its branch office 20 minutes from campus. The participating faculty were mostly young PhD's with little or no prior design experience whatsoever. The young ones agreed to join the team grudgingly! The reason for their disinterest in the capstone design is that the amount of work required is not represented by the credit assigned to the course. However, all agreed that young faculty participation is a good experience that adds to their design knowledge.

The Restructured Capstone Course: The final format of the *restructured* course was made up of:

- *general lectures*: offered on a weekly basis, intended to define goals, expose students to: design procedures, codes, and the dynamics of the process,
- *Project information kit*: selection criterion, project definition and description, sorting out field data, design methods, cost estimation, scheduling, standards/ test methods, and applicable software,
- *Coordination, collaboration, and management*: individual assignments versus team-based, decision making, coordination of multiple tasks, functioning as a team member, and arrival at the final design.

In the first semester of its implementation, several issues had to be ironed out with regard to: running the course, assigning instructional tasks, clarifying the role of each individual amongst the parties involved, and attempting to reduce barriers and unanticipated delays. Coordinators (practitioners and young faculty) were keen in insuring that students would not be facing obstacles due to misunderstanding, or lack of resources and/or logistical support. Senior standing was the primary prerequisite for allowing students to take the course. The normal course duration is one semester extendable to two semesters. Deciding on a suitable design project was the most challenging task experienced by teaching staff and students. The reasons are that the project has to fall within the area of interest that the team (group of four to five students working together) has designated as their primary area of interest. And, at the same time, has to be drawn from the locale, with practical overtones. The following are additional, agreed upon guidelines:

- Select projects that are relevant, challenging, yet feasible,
- Select projects that have good chances for successful completion during the semester,
- Insure that background information, field data, etc. are available and at the disposal of the students,
- Make use of design methods and standards used locally or regionally,
- Try to make use of prerequisite analysis and design courses, as much as possible.

Three projects' titles that were successfully completed during the first semester, following the adoption of the restructured course plan, are shown in Table 1.

A reasonable scenario for moving the process forward and getting the selected project done on time is comprised of the following stages and/or steps:

1. Preliminary activities: During the first two weeks, team members get together to find out the skills they possess that could be deployed in performing required tasks. This is the time for "fact finding"! They meet with the advisor(s), to arrive at the schedule and the strategy to accomplish the mission. Should also arrive at a consensus of the tasks that need to be performed.

2. Primary activities: During this stage, which lasts for about ten weeks, the bulk of the design work and related activates are executed. Each team member avails himself/herself roughly 20 to 30 hrs /week to do what had been agreed upon during the Preliminary stage.

Table 1. Typical titles & scopes of three projects under the restructured course plan.

Area	Title	Scope	Other
Structures	Two story residential building	To plan, design, and detail the structure adhering to local design codes	Concrete structure
Structures	An annex to an existing office building	To plan, design, and detail the annex building adhering to local codes	Steel structure
Transport	A 20.0 km asphalt paved rural road with two interchanges	To plan, design, and detail the road and its interchanges using locally applicable standards	Low volume rural road over highly cemented sand subgrade

During the *Primary activities*, students are usually tense, under pressure, and some find it necessary to drop one or two courses from their semester schedule to avail themselves for the tasks they have agreed to undertake. During this period, the students do their individual search, hit the books and notes of the prerequisites, seek advisor(s) council, arrive at their own version of the design, get their design checked by their team members, and eventually arrive at the first draft of their design.

3. End of project activities: This is the stage when the design is finalized. The final written version of the design is submitted to the Committee for processing, evaluation, and followed by oral presentation attended by faculty and students; that usually last for one hour followed by a question and answer period. All team members are supposed to take part in the presentation. The system allows the instructor(s) to assign an individual grade for individual performance as well as a team grade for team performance. At the end, an evaluation form is handed out to all attendees seeking their feedback about the project and its presenters.

At the end of each semester, students are asked to express their opinions in writing, asking specifically about the shortcomings they have encountered during their participation in the course. Students' suggestions are always taken seriously, and based on their input, modifications to course format have been incorporated.

Evaluation of the Restructured Design Course: After three consecutive semesters of offering the course in the new format, the majority of participants have felt that the course has benefited all involved. Benefits can be identified relative to the three participating groups, namely: students, faculty, and the industrial partners. Issues that relate to the academic setting, in general, and the curriculum in particular, are also outlined below.

1. Students' benefits: In addition to many intangible benefits, the restructured course has impacted students in three different ways:

i) *Exposure to professional practice:* Through the interaction with the practitioners plus site visits, students get exposure to the work environment of the firm. Frequent contacts with the practitioners, gives students a close look at actual engineering tasks and the demands placed on practicing engineers.

ii) *Exposure to real engineering design:* The nature and type of projects selected plus the guidance provided by the industrial partners, versus made-up projects, usher students into practical design and compel them to apply methods in use by firms in the Region. This exposure adds flavour and familiarizes students with the practice.

iii) *Working as a member of a team:* Another important benefit is to learn how to function as a member of a team before entering the work force- an essential skill of today's engineers. Unfortunately, all students have entered the capstone design course with no prior experience in team membership skills. As a result, many have encountered initially some form of interpersonal conflicts that were eventually minimized.

2. Faculty benefits and related issues: The young civil engineering faculty who participated in the capstone design course have made some gains as a result of their participation and exposure to unfamiliar territory that their prior academic journey has not adequately prepared them for. Many who have taken the time to support the capstone experience as co-advisors, have found it to be worthwhile, and have become interested in continuing their involvement in the course. The inclination today of young professors (recent graduates) to specialize in a specific area leads many to a

modularized type of teaching. The *efficient* instructor soon develops a neat 50 minute package of notes for each lesson. Orderly course notes that change infrequently are used. Problems and tests arranged with all variables 'given' and only one correct answer are easy to teach, and more importantly, easy to grade. The modularized teaching approach provides the professor with more time for his research activities which are the only vehicle, today, for faculty promotion. The question is: How to "entice" young faculty to become proactive in capstone design courses, and, at the same time, allow them to carry on with their research?

3. Feedback on students' preparation via the curriculum: An important by product of the course has been the feedback provided by the students, as well as faculty own findings as advisors, with regard to: the curriculum, students' preparation or lack of it, and deficiencies to be addressed. The notable points are:

i) *Technical writing skills:* Reviews of written submissions has shown lack of technical writing skills among the students. Although not totally unanticipated, the severity of the deficiency has triggered curricular changes, i.e., to add more effective writing experiences.

***ii*)** *Public speaking:* The oral presentations made by the students have indicated lack of experience in their abilities to express themselves properly and eloquently. Steps have been taken to incorporate a public speaking component in the prerequisite junior courses.

iii) *Dealing with data and statistics:* The involved faculty have noted that most team mates have poor perception of how to handle data and make use of their prior knowledge in probability and statistics. This has amplified the need for more relevant examples in the probability and statistics course that students take during their second year. Also, encouraging students to take an additional course in the area of probability and statistics, as a technical elective, would go far in enabling students to handle engineering-type data more proficiently.

iv) *Reshuffling design topics in prerequisites:* In the process of designing various structural members for buildings, etc., the staff have noted discrepancies in design prerequisites: such as: a) the need to realign subjects, i.e., to have the topics properly sequenced and, b) to introduce students to regional design practices.

v) *The infusion of design concepts in a first-year introductory course:* A first year engineering course titled "*Introduction to Engineering*", intended to shed light on the role of engineers, was revamped, i.e., allocating 30% of its content to introductory design concepts. Triggered by the curricular disconnect with first year students, who do not get any exposure to design until their third year. The new course was well received and served the intended purpose rather well.

4. Practitioners' benefits: At the outset, there seems to be little incentive for the voluntary participation by the consulting firm and its staff members (the practitioners) aside from the lofty ideals of professionalism, alma mater altruism, etc. However, as expressed by the top brass in the firm, tangible benefits may be derived from their participation in the capstone design, including:

i) *The academic setting:* An obvious direct benefit for the practitioners is the opportunity to air out their views and exchange design concepts with faculty members.

ii) *To help recruit graduates:* This type of involvement gives the firm the opportunity to know future graduates, and helps in recruiting future engineers. Some students have received job offers from the same firm with whom they worked in the senior capstone course.

iii) *Industry driven education*: The opportunity for the industrial partner to provide input on design education, has contributed to improvements in the execution of the capstone design course. An indication of the success of this format is the interest that industry has in graduates who have been through the restructured capstone course

Summary and Conclusions

The paper reports on a partnership between academics and practitioners in developing and teaching a senior civil engineering design course at an international university, where practitioners played a major role, in planning and teaching the capstone design experience. Development of the course plan coincided with a departmental decision to revamp and update an existing senior design course, to more effectively convey the concept of design and to expose students to professional practice. The restructured capstone course, co-taught by a local consulting firm, has met stated objectives, i.e., to assert that design is a *thoughtful* process that depends on: solid engineering background, intelligent generation of design concepts, and arrival at relevant specifications to realize the design concepts. As a consequence, students have gained good insights into the "nuts and bolts" of design in their locale, and have acquired skills to enter the practice. This industry-driven capstone experience has provided valuable feedback regarding curriculum and potential capabilities of graduates. In a way, the capstone experience has served as a microcosm of the four year program, and provided insights into curricular changes to improve design education.

References

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