AC 2010-2035: PROJECT-ORIENTED CAPSTONE DESIGN IN CIVIL ENGINEERING: LINKAGES WITH INDUSTRY TO ENHANCE THE PRACTICE

Waddah Akili, Iowa State University

Project–Oriented Capstone Design in Civil Engineering: Linkages with Industry to Enhance the Practice

Abstract: Teaching civil engineering design through senior projects or capstone design courses, with industry involvement and support, has increased in recent years. The general trend toward increasing the design component in engineering curricula is part of an effort to better prepare graduates for engineering practice. While some design projects are still of the "made up" type carried out by individual students, the vast majority of projects today deal with "real-world problems" and are usually conducted by student teams. The paper begins ***first*** by briefly reviewing the design as a "thought" process, focusing on several dimensions of "design thinking" and how "design thinking" skills are acquired. ***Second,*** the paper reports 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 from the Region, 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 departmental graduates. In a way, the capstone experience reported on in this paper, serves as a microcosm of the four year program. Experiences and outputs from the course can be used to provide guidance and insights into curricular changes, teaching methods, and exposure to civil engineering practice in the Region; and helps in establishing enduring connections with the industrial sector.

Introduction

Design is widely considered to be the central and the most distinguishing activity of civil engineering. It has also long been understood that engineering institutions should graduate engineers who could design effectively to meet societal needs. Historically, engineering curricula have been based largely on an "engineering science" model, referred to as the "Grinter Model", in which engineering is taught only after a solid basis in science and mathematics. The resulting engineering graduates were perceived by industry and academia, at the time, as being "ill-prepared" for the practice. Despite steps taken to remedy the situation, through greater industry-academia collaboration; both design faculty and design practitioners argue that further improvements are necessary. Design faculty across the country and across a range of educational institutions still feel that the leaders of engineering schools (deans, department heads, tenured faculty) are unable or unwilling to recognize the intellectual complexities and resources needed to support good design education.

Fortunately, more and more educators are becoming aware of the issues of design, and steps are being taken world wide, to address the concerns of industry at large. One approach has been to form "symbiotic" partnership between industry and academia through senior capstone projects. The capstone course has evolved over the years from "made up" projects devised by faculty to industry-sponsored projects where companies provide “real” problems, along with expertise and financial support. In fact, design courses, in general, have emerged as a means for students to be exposed to some flavor of what engineers actually do and also could learn the basic elements of the design process by being involved in real design projects.

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 capstone course, co-taught by a local consulting firm, has met, in principle, the objectives behind the desired change, and asserted that design is a series of interconnected and *thoughtful* processes that depend on: solid engineering background, intelligent generation of design concepts, and arrival at relevant specifications that make it possible to realize the design concepts. This industry-driven capstone experience has provided valuable feedback regarding curricular content and potential capabilities of graduates. In a way, the capstone experience reported on in this paper, has served as a microcosm of the four year curriculum. Experiences and outputs from the course have been used to usher the teaching process and provide information on future curricular changes deemed necessary to improve design education, to better prepare graduates to meet the projected needs of industry in the Region.

Review

What does “design” mean in an engineering context? What are the qualifications of a designer? Can design be taught? And if so, who can teach it? These questions will be addressed in the paragraphs that follow.

Relevant Definitions, Thoughts and Processes: *Engineering design* as stated by Dym et al. in 2005 is: “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” (1). This definition presents design as a thoughtful process that depends on systematic, intelligent generation of design concepts and the specifications that make it possible to realize these concepts (2). Sheppard’s characterization of what engineers as designers do: “They scope, generate, evaluate, and realize ideas” (3). In the context of engineering design, creativity is important, but it is not design! *Design problems* do reflect the hard fact that the designer has many constraints that may positively or negatively affect the outcome of the design, i.e., the designer has a client to satisfy and for whose benefit the item/artifact and/or project is being developed.

There are many approaches to characterizing *design thinking* and *design processes*. These characterizations, often associated with good designers, would include the following:

- view design as an inquiry and/or iterative loop of divergent–convergent thinking,
- focus on the “big picture” in all stages by including systems thinking and systems design,
- handle uncertainties that are likely to arise,
- arrive at decisions,

- think and act as a member of a team,
- think and communicate using known languages of design,
- be familiar with relevant background and technical knowledge that lead to successful design.

The starting point of any design project, irrespective of the object or nature of the project, is the *problem definition phase* characterized by asking relevant questions and attempting to find plausible/realistic answers. No sooner has a client or professor defined a series of objectives for a design project than the designer- whether in a consulting office or in a classroom- want to find out what the customer really wants. Questions such as: what is an economic project? How do you define the best design? What is a safe design? What are the factor(s) that will affect the design the most? Phrasing it differently, knowledge resides in the questions that can be asked and the answers that can be provided (2) .A sequence of inquiry characterized by a hierarchy: certain questions need to be asked and answered before other questions can be asked. There is a set procedure which constitutes the inquiry process in an epistemological context. Taxonomies of such a procedure or inquiry process have been extended to computational models (4) , to the intricacy between asking and learning (5) , and would also apply to the questions students ask during a class and/or tutoring session(6).

There are two classes of questions within a design context; the first is the category of questions that do have a specific answer, or a specific set of answers. Such questions are characteristic of *convergent thinking*, where the questions attempt to converge on and reveal “facts”. As such, answers to converging-type questions are expected to be truthful and verifiable. The second category of questions is diametrically opposite to the first, and is characteristic of *divergent thinking*, where multiple alternative known answers exit, regardless of being true or false. The key distinction between the two types is that *convergent* questions operate in the knowledge domain; whereas *divergent* questions operate in the concept domain (1) .This has strong implications for teaching conceptual design thinking, since concepts need not be truthful or have true value, whereas knowledge does indeed! Design thinking, therefore is seen as a series of transformations from the *concept domain* to the *knowledge domain*. Such questioning and thinking is the “backbone” of any design process, and the major tool by which designers add to the pool of engineering knowledge (7) .The significance of the transformations between the concept and knowledge domains is further supported by the finding that the combined incidence of deep reasoning questions and generative design has been shown to correlate positively with performance in arriving at design solutions (8).Therefore, any properly produced design is preceded by effective inquiry that includes both a *convergent* component (lower level and deep thinking questions) and a *divergent* component (generative design questions intended to create the concepts upon which the design is based).

The forgoing discussion raises questions relevant to teaching design in general and civil engineering design in particular. Clearly, the *divergent* inquiry in design thinking is neither recognized nor included in most engineering curricula. I think the time is right to introduce the iterative *divergent-convergent* process(s) to develop better pedagogical approaches to engineering design.

Beaming at Design-Related Education: Recently, designers, throughout the world, have helped develop an increasingly complex “built” environment that includes some major large-scale civil engineering projects. Simultaneously, designers have been pushing the envelop at relatively fast rate making products, systems and civil engineering projects increasingly more complicated as they strive to improve reliability and increase service-life by increasing number of components and their interdependencies. Further, designers have to expand the boundaries to include environmental factors, social impacts, and public safety issues in their designed systems and projects. The trends today suggest that engineering designers are in need of skills and experience to help them cope with the complexity and facilitate the arrival at optimum design. Invariably, this type of: knowledge, skills, and related experience need to find its way to the classroom through curricula updating, proper counseling and mentoring, and insuring a conducive class environment.

There are four aspects of design education believed to be of relevance to acquiring and/or enabling young designers, and students in particular, to embark on the mission. The four are highlighted in the sections to follow.

1) Thinking about a system’s approach: A good designer is some one who can anticipate and deal with intended and unintended consequences resulting from interactions among the multiple factors of the system. Exposure to system analysis and system dynamics – preferably through a rigorous course(s) - would assist the designer in sorting variables, prioritizing, and managing the design process. Unfortunately, these skills are not common, do require prerequisites, and regarded by most as difficult to learn. Many different teaching methods have been proposed to improve people’s abilities to grasp and retain knowledge under this category. Recognizing that there are difficulties in proper delivery of systems analysis and systems dynamics to civil engineering students; the fact remains that these tools are extremely useful for someone who plans to become a designer. Therefore, ways have to be found to enhance the understanding of systems’ thinking, and at the same time, to develop educational experiences that could efficiently improve learning outcomes.

2) Looking at risk management and uncertainty: Engineering design is carried out relying on incomplete data, imperfect models, often with unclear objectives, and other potential problems and constraints. The effects of such uncertainties on the design of a project may have serious consequences unless proper safeguards have been undertaken based on probabilistic and statistical approaches to design and factors affecting design. Some have argued that current undergraduate curricula greatly underemphasize the theory and application of probability and statistics in engineering (9) .Research has revealed that people are generally prone to serious errors in probabilistic and statistical thinking, including neglect of prior probabilities, insensitivity to sample size, and misconceptions of regression (10) .The formal course work in probability and statistics falls terribly short of exposing engineering students to various encountered errors, e.g., systematic underestimation of uncertainty. Engineering educators are concerned, and some have been working to alleviate the difficulties by stressing conceptual understanding, emphasizing active teaching methods, and using more graphics & simulations. (11) There is a long way to go with regard to uncertainty and the way it ought to be handled in the classroom. Suggested improvements and changes have included the following: (12)

- offer probability and statistics courses early on in the program,
- include “uncertainty” and its implications in engineering analysis courses,

- consider offering technical electives, in this domain, and let "uncertainty" be a central theme,
- make use of modern computational tools to support probabilistic thinking.

Such curriculum changes may fall short of meeting set goals without adequate research aimed at continued improvements in probabilistic and statistical thinking for civil engineering in general and the design component in particular.

3) Estimation: A main challenge of a project design is the number of variables and their interactions during the design process. Often, the system stretches beyond designers' capability to grasp all of the details simultaneously (1) .One strategy for coping with the many variables is to bring the system back within the limits of human mental capacity by focusing selectively on a limited number of factors, preferably the most significant ones. Designers are usually good at estimation. They are able to size up parameters, sort them out in terms of their relative importance, and neglect the ones that have less impact on the project. Today's graduates are not good at estimation (1) .This poor performance by the new graduates appears to be related to a weak conceptual understanding of basic engineering science, limited ability to form appropriate analogies, weakness in visual perception, short-term memory, and insufficient interaction with their physical surroundings. Additionally, current engineering education emphasizes sophisticated methods for precise calculation and thus may underemphasize approximation skills(13).Attempts to rectify the situation would require research and development and eventually instigating potential changes in curricula and teaching methods.

4) Physical modeling and experimentation: Unfortunately, the advent of the computer and its impact on teaching engineering has made it easy to produce computer-based models at the expense of physical models. This fact is behind a general trend of teaching applied engineering subjects with minimal students' involvement with physical set-ups including laboratory experiments. Carrying out laboratory experiments and generating experimental data, visiting a project site, and using pencil and paper to produce a schematic, are gradually fading away. These traditional tools were instrumental in developing an engineering common sense. It is argued here that generating data from physical models is potentially a great learning tool, particularly when the model is built by the students. Building a model, testing a model, generating physical data from the model, and analyzing said data, help students alternate between *inductive* and *conductive* processes, thus broadening their design vision and their understanding of the experimental approach to engineering design. There is potentially a real need to research the ways to teach engineering students how to make proper use of physical models and experiments.

The four aspects (discussed above): thinking about a systems approach, looking at risk management/uncertainty, estimation, and physical modeling and experimentation – are intended to pin point some shortcomings in design-related education that need to be addressed using a principled approach to dealing with these issues.

Common Structure of a Capstone Design Course

The general structure of a capstone design course depends largely on the objectives of the course and the level at which the course is implemented. There are several levels at which design courses can be offered: i) the engineering *college level*, ii) the engineering *program level*, or, iii) the engineering *stem level*. A design course at the engineering *college level* may include students from any engineering discipline within the college; a course at the engineering *program level* includes students from one department or discipline in the college; and a course at the engineering *stem level* focuses on one specific area within the particular department or discipline. For example, a design course at the *college level* might involve students from civil engineering and other departments as well. A design course at the *program level* would be restricted to civil engineering students; while a course at a *stem level* would involve civil engineering students with a specific concentration within civil engineering such as: structural, transportation, or environmental engineering. The majority of capstone design courses, however, appear to fall in the engineering *program level* category.

The structure of capstone design courses do vary significantly from one college to another. Also, there are some variations between one department and another. But nearly all have the same basic objective: providing students with experiential learning activities that satisfy set criteria, i.e., in the US, it is ABET Design requirements that need to be met (14).The ABET requirements must include some of the following: *"development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternative solutions, and detailed system description. Further, it is required to include constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact. Courses that contain engineering design normally are taught at the upper-division level of the engineering program. Some potion of this requirement must be satisfied by at least one course which is primarily design, preferably at the senior level, and draws upon previous coursework in the relevant discipline*". (14)

A proliferation of capstone design experiences, over the last decade, has taken place at many colleges of engineering – all seem to meet some of the requirements noted above. The ABET requirements is the common thread that links all such experiences for all engineering disciplines, throughout the US, and also in some other countries that have chosen to use ABET's requirements.

Another factor that has influenced the development of capstone design experience has come from the needs of the industrial sector. Capstone design courses have been developed to better prepare students to meet the requirements of industry, by emphasizing design and the practice. To try to satisfy the needs of industry is a central issue of nearly all design courses, and capstone-type design in particular. Industries have often promoted senior-level project courses by providing funding, equipment, and expertise. Other forms of support include providing awards and incentives to participating students who excel in their work. Some industries also provide assistance in projects' evaluation. In the US, industrial sponsors, by and large, appoint a liaison engineer to assist students and follow the progress of the project. The involvement of a liaison engineer is a positive step in achieving success. Having students feel responsible and accountable to an industrial "customer" seems to be an important factor in developing self-confidence and interpersonal skills, and learn about engineering practice. The success of a project can often be assessed by the frequency of interaction between liaison engineers and students (4, 13) .Opinions vary as to the validity and effectiveness of industry-sponsored projects. Those in favor of industry- sponsored projects insist that students will not know what *real engineering* is like unless they work on a *real world* problem. On the other hand, those opposed to industry-sponsored projects argue that many such projects are not true engineering and often contain low level analyses that do not add anything new to students' knowledge and skills. Industry may also have little sympathy for students' schedules, course loads, and other commitments and restrictions that could interfere with project completion (15). It may also be hard to find an industry-sponsored project that meets declared project requirements than it is to make up a project that is tailor-made for a specific course or set of courses. Despite the differing views, industry-sponsored projects continue to be a major source of capstone design activities and seem to be increasing in number.

Reporting on the Experience

Here, the author describes the pros and cons of a restructured capstone design course at an International University, and reports on the experience under three headings. ***First***, sheds light on causal factors that lead to restructuring the design course. ***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, and reported on here: is to have the senior-level students' work on group projects under the guidance of faculty members in their area of specialization (i.e., structures, transportation, environmental, geotechnical). Students were required to adhere to a specific format in meeting course requirements, including: adherence to a pre-set schedule in performing the required tasks, meeting with the faculty member(s) on regular basis, submission of a mid-semester report and a final report, and an oral presentation at the end of the exercise. Oral presentations are evaluated by all those in attendance. The overall course grade was based principally on reports' grades given by the faculty member(s) who guides the student throughout the course/project. i.e., less weight was given to presentation evaluations. The above format was problematic and was not looked upon favorably by faculty, students, and administration. The major concerns include:

1) Great deal of variation in terms of efforts and time spent by the student, and demanded by the guiding faculty during the entire course duration, i.e., some faculty were harder and much more demanding than others.

2) Most students were apprehensive when their turn came to register for the senior design course. They were concerned and mindful of working harder than usual, and not reaping the benefits that should come with hard work! (i.e., inequitable work product or outcomes associated with different projects and/or guiding faculty members).

3) Young inexperienced faculty members, who were more inclined towards analysis rather than design, were not prepared or sufficiently capable in providing the guidance/technical support required to fulfill the mission, i.e., do not give the design venue the weight it deserves!

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 and/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, i.e., had no bearing or connection to real design issues in the locale.

6) Although students were supposed to be working in teams, many had problems attributable to lack of experience in either team membership or leadership. As a result, students encountered interpersonal conflicts that adversely affected outcome. Thus, individual effort of a student on a project was difficult to identify and reward.

As can be noted from the discussion above, there were serious deficiencies in the capstone design course 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, the supervision and technical support of *practitioners*, effective *teamwork*). Also, alumni feedback indicated that the course did little to prepare students for professional practice. The unofficial general consensus amongst departmental faculty members was to revamp the existing capstone design course in favor of a new course- to do away and/or reduce the pitfalls indicated earlier. Finally, the impetus for changing the format came from three groups: the civil engineering faculty, senior students, and some of the recent civil engineering graduates who wanted to share their impressions based on their own experience as students in the capstone design project. After several meetings (mostly open forum), attendees have unanimously 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 major action items:

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, and are located within a short distance from campus,
3. The course should address some relevant non-technical topics associated with civil engineering design such as: ethics, litigation, finance, social impact, etc.,
4. Insist on teamwork and allow students to select their own team members,
5. Written and oral presentation should be required of each individual, and
6. Final course grade should 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, i.e., a person or two with the right kind of design experience; ***or*** delegate the responsibility to a competent consulting firm in the vicinity , who would be 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. At the end, and after an extensive search, the decision was made to delegate the responsibility to a medium-sized multidisciplinary firm with its branch office 20 minutes from campus. The participating faculty, with the exception of one, were mostly young PhD's with very little or no prior design experience whatsoever. The young ones agreed to join the team grudgingly! The main reason for the disinterest of the young faculty members in the capstone design course, is that the amount of work required for such a course is often not represented by the credit assigned to the course. Some faculty members avoid getting involved because it bears no connection to their scholarly activities. However, all agreed that young faculty participation is a good learning experience that they need to capitalize on, i.e., it would enhance their capabilities and add to their design knowledge.

The Restructured Capstone Course: The final format for the *restructured* course was made up of three elements, i) *general lectures*: to be offered on a weekly basis and intended to define goals, expose students to the general framework, introduce applicable design procedures and codes, shed light on coordination of multiple tasks, and the dynamics of the design process, ii) *project information kit*: selection criterion, project definition and description, sorting out field data, design methods, cost estimation, scheduling, applicable standards and test methods, and use of applicable software, iii) *coordination, collaboration, and management*: individual assignments versus team-based, decision making, coordination of multiple tasks, how to function effectively as a team member, and arrival at the final design.

During 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 eliminate barriers and delays. Course coordinators and teaching staff (practitioners and young faculty) were keen in insuring that students would have “easy sailing” and 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, if the need arises. Deciding on a suitable design project was one of the most challenging tasks experienced by teaching staff and students. The reasons are that the selected project has to fall within the field (area of interest) that the team (group of four to five students willing to work together) has designated as their primary area of interest. And at the same time, the project has to be drawn from the locale, with practical overtones. The coordinator (guiding practitioner and/or faculty member) has to make sure that required resources for completing the selected project are readily accessible or within reach. Additional guidelines that were agreed upon are noted in Table 1. Examples of selected projects’ titles that were successfully completed during the first semester, following the adoption of the restructured course plan, are shown in Table 2.

- The projects should be challenging, yet feasible,
- The projects should have good chances for successful completion during the semester. Limit the scope to a level that is appropriate for the duration,
- Insure that pertinent literature, background information, field data, etc. are all available and at the disposal of the students,
- Make use of design methods used locally or regionally,
- Rely on standards applied locally or regionally,
- Try to make use of prerequisite analysis and design courses, as much as possible,
- Instructors/advisors should be allowed to incorporate those aspects of the design - into a project - which they feel are important and contribute to students’ learning.

Table 1. Some additional guidelines for capstone design projects.

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 would get together, get to know each other, find out the skills that they possess and could be deployed in performing required tasks. This the time for “fact finding”! Sitting down with the advisor(s), they need to

come up with the schedule and the strategy to accomplish the mission. During this stage, they should arrive at:1) the tasks that each individual will perform, 2) when, and how often they would meet to compare notes, and huddle to come up with collective decisions, 3) finalize arrangements for team-advisor(s) interaction with regard to: the frequency and schedule of meetings, arrive at a broad-based view of the multiple tasks that need to be performed, finalize meeting schedule with advisor(s) and the way to get their feedback on regular basis.

Area	Title	Scope	Particulars
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
Transportation	A 20.0 km asphalt paved rural road with two interchanges	To plan, design, and detail the road and its interchanges using locally applicable methods & standards	Low volume rural road over highly cemented sand subgrade

Table. 2. Typical titles & scopes of three projects under the restructured course plan.

2) Primary activities: During this stage, which usually lasts eight to ten weeks, the bulk of the design work and related activates are carried out. Each team member avails himself/herself roughly 20 to 30 hours per week to do what had been agreed upon during the *Preliminary stage*. During this period, labeled here as *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, to get the project work done on time. During this period, the students do their individual search, hit the books and notes of the prerequisite courses in analysis/design and other related subjects, seek advisor(s) council on virtually all aspects of their design scenario, arrive at their own version of required design, get their design checked by their team members, and eventually arrive at the first version, or iteration, of their design. The advice/suggestions and guidance provided by the adviser(s) on a routine basis, is instrumental in arriving at a proper design, i.e., a design that would be acceptable as it meets required standards.

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

At the end of each semester, and after giving each student his/her grade, students are asked to express their opinions in writing - asking them specifically about the deficiencies and shortcomings they have encountered during their participation in the course. Students' comments, views, and 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 format and structure described above, the majority of participants feel the course has benefited all involved. Several benefits of the restructured course 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.

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 (who have provided guidance/advice and supervision), plus site visits, the students get exposure to the working environment of a professional engineering design firm. Frequent contact with practitioners, providing advice and technical support, throughout the semester, gives the students an intimate look at the way actual engineering tasks are performed 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 understand and apply methods in use by firms in the Region, which is likely to be different than what they have learned in the prerequisites. This exposure adds flavor and familiarizes students with the practice in the Region.
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. Another reason for choosing team-oriented capstone projects is to get some exposure in handling larger projects. 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 properly addressed, at a later stage, and eventually minimized.

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" (16) .The modularized teaching approach provides the professor with more time for his/her research activities which are the only vehicle, today, for faculty advancement and promotion. The capstone courses are structured so that such a teaching approach is neither possible nor practical. The question that needs to be answered: 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?

Feedback on students’ preparation via the curriculum: A very important byproduct of the course so far has been the feedback provided to the faculty by the students, as well as faculty own perceptions and findings as advisors and examiners, with regard to: the curriculum, students’ preparation or lack of it, and deficiencies that need to be addressed. The most notable points are:
i) Technical writing skills – Reviews of written submissions by team members has indicated a severe lack of technical writing skills among the students. Although not totally unanticipated, the severity of the deficiency has called for curricular changes to incorporate 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. This deficiency needs attention, and some steps have been taken to incorporate a public speaking component in two of the prerequisite sophomore/junior level 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& 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, the teaching staff have noted two discrepancies in design prerequisites: a) the subjects need to be realigned i.e., to have the topics properly sequenced; and, b) the need to introduce the students to local/regional design practices, making use of local codes. A strong argument has emerged with regard to the timing of the capstone experience. Many have argued that capstone courses occur much too late in an engineering student education (?).
v) The infusion of design concepts in a first-year introductory course - A first year engineering course titled *“Introduction to Engineering”* intended initially to give students some historical perspectives about engineering and the role of engineers, was later revamped in response to a proposal by the Capstone Design faculty to allocate about 30% of the course topics to introductory design concepts, and civil engineering design venues, in particular. It was motivated by an awareness of the curricular disconnect with first year students who often do not get to see engineering faculty or have any exposure to design until the third year. The modified course has been well received by students and appears to have served the intended purpose rather well.

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, several tangible benefits may be derived from their participation in the capstone design course. These include:

i) The academic setting-An obvious direct benefit for the practitioners involved is the opportunity to air out their views and exchange design concepts and ideas with the faculty members. This is the kind of drill that many practitioners/designers wish to get into, i.e., to test their ideas and check their feasibilities.
ii) To help recruit graduates –This type of involvement gives the firm the opportunity to get to know future graduates, their capabilities; and may help the firm 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 regarding students' education, has contributed to curricular changes and further improvements in the execution of the capstone design course.

As expected, the new format of the capstone design course has been praised by the industrial partner (the consulting firm) and has also generated enough interest in the locale that we have been able to recruit a second firm. In fact, another college in the Region has recently decided to use the same format. A good 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 current trends in engineering education have resulted in an increased use of class projects for teaching engineering design. Senior level capstone design courses, with industry involvement, are gaining popularity in nearly every discipline of engineering. In many schools, capstone design courses have undergone dramatic changes in collaboration with the industrial sector, in an effort to bring the practical side of engineering back into the curriculum.

The paper reviews, ***first***, the role of design in engineering curricula, identifies several dimensions of design thinking, looking particularly at divergent-convergent model, and sheds light on design–related education issues. The paper also describes the common structure of a capstone design course, and identifies those factors that influence the development of the course, the most.

In the ***second part,*** the paper reports on the development and execution of a senior design civil engineering course at an international university, where practitioners played a major role, side by side with faculty members, in planning and teaching the capstone design experience. Development of the course plan coincided with a departmental decision to revamp and update the 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 that make it possible to realize the design concepts. This industry-driven capstone experience has provided valuable feedback regarding curricular content and potential capabilities of graduates. In a way, the capstone experience reported on in this article, has served as a microcosm of the four year curriculum, and at the same time, provided insights into future curricular changes necessary to improve design education of the students.

The teaching partnership between academics and practitioners has resulted in a totally new experience for the students. Senior students, working in teams, have produced engineered solutions to real design problems, with an understanding of the socioeconomic, environmental and political implication of their work. As a consequence, students have gained good insights into the "nuts and bolts" of design in their locale, and have acquired skills needed to enter the practice.

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