Practitioner Driven Senior Design Capstone Course

Anant R. Kukreti [1], Raviteja Chalasani [2]

Abstract - **In the United States a capstone design experience is a senior year course in which students draw upon various aspects of their undergraduate coursework to develop a comprehensive, engineered solution to an open-ended problem. This paper describes a capstone design course conducted in the Department of Civil and Environmental Engineering (CEE) at University of Cincinnati (UC), Ohio as a three quarter Integrated Design Sequence (IDS) course. IDS is an innovative and ambitious three course series focusing on a single design theme with multiple components that encourage interaction among traditional CEE specialty areas, viz., construction, environmental, geotechnical, structural, transportation, and water resources. The 2006-2007 IDS project is focused on the redevelopment and conversion of approximately 130 acres of the city of Blue Ash airport into a recreational park. Students work in design teams, like in a design firm, and submit feasibility, design and construction plans, and associated cost estimates for the project. Students must interface with a "client" and a group of "industry advisors" or practitioners, who collectively act as owners, to gather information. The whole experience stresses on communication and collaborative skills, and serves as a gateway to the profession.**

Index Terms - Capstone course, Civil Engineering, Practitioner-driven, Real-world.

INTRODUCTION

The capstone design experience in an undergraduate engineering degree program is a course in which students draw upon various aspects of their undergraduate coursework to develop a comprehensive, engineered solution to an open-ended problem [1]. Since Autumn Quarter 2000, the capstone senior design course in the Department of Civil and Environmental Engineering (CEE) at University of Cincinnati (UC) is executed as a three-quarter Integrated Design Sequence (IDS) course, offered in conjunction with a practicing professional engineer (client), and other practitioners and faculty members acting as mentors. IDS is an innovative and ambitious three-course series focusing on a single design theme with multiple components that encourage interaction among traditional CEE specialty areas (e.g., construction, environmental, geotechnical, structural, transportation, water resources). Students work in design teams, like a design firm, and submit feasibility, design and construction plans, and associated cost estimates for a real-world project. Students must interface with a "client" and a group (consisting of 6 to 8 members) of "industry advisors" or practitioners (who collectively act as owners) to gather data and information; the owners are also in the audience for final presentations. A special design center houses all the teams. The whole experience stresses on communication and collaborative skills. This course is designed as a gateway to the profession. The deliverable each quarter is a set of plans with a written report. For the autumn quarter, the drawings show a conceptual plan. The product of the Winter Quarter is a set of design plans with details, specifications, quantities and a construction cost estimate, and the product of the Spring Quarter is a set of design plans simplified for better understanding by a non-technical audience. This paper describes four aspects to the IDS course:

- description of the course goals and implementation;
- a description of the projects executed;
- grading process used; and
- assessment of the project outcomes, objectives, and results.

Hopefully, this documentation will help others in planning similar experiences for senior engineering students.

DESCRIPTION OF THREE-PHASE SENIOR DESIGN PROJECT

Course Goals

All CEE undergraduate students at UC are required to take Integrated Design Sequence (IDS) I, II, and III. These courses were included in the curriculum to provide a final, integrated engineering experience for the students and to meet the General Education requirements of the University. The courses are spread over three quarters to allow the students sufficient time to complete a significant project. The goals of the IDS courses are:

1. To show students how engineering concepts, taught as individual subjects in disparate courses, are brought together in a project.
2. To demonstrate the interaction needed between CE sub-disciplines in a project.

[1] Associate Dean & Professor of Civil Engineering, University of Cincinnati, PO Box 210071, Ohio 45221-0071, U.S.A., anant.kukreti@uc,edu
[1] Graduate Teaching Assistant, Department of Civil & Environmental Engineering, University of Cincinnati, PO Box 210071, Ohio 45221-0071, U.S.A., chalasr@email.uc.edu

3. To provide training and experience on teamwork and team building, essential for modern engineering practice.
4. To improve oral, written, and visual communication skills.
5. To force students to consider non-technical aspects of a project, such as: 1) Cost; 2) Time schedules; 3) Political considerations; 4) Social responsibility; 5) Ethical issues, and 6) Diversity/Community values.
6. To introduce technical material not covered in coursework.

Selection of Design Teams and Management

The senior class is split into independent design teams (typically there are 6 to 7 students per team). Teams are encouraged to operate as an engineering consulting firm. Each team is led by a project manager and a deputy project manager who are responsible for the deliverables. An effort is made to have at least one student in each team from each of the specialty areas (structures, geotechnical, transportation, construction, and environmental). All students before the end of their junior year are required to complete an online form documenting their desired specialty area. Team members are expected to contribute in their area of "expertise" and also to develop an understanding of how all elements of the project fit together in the final design package. Project managers and deputy project managers are selected before the beginning of the school year at a combined meeting of faculty and industry mentors. Material available to aid the selection process has primarily been student resumes from co-op jobs with input from faculty and industry mentors based on personal knowledge of candidates as well as grade records. (The undergraduate engineering degree program at UC is a five-year program, and students complete six quarters of required co-op training before their senior year.) A questionnaire is sent out to all incoming seniors explaining the program and assessing interest of each individual to serve in a leadership position. This reduces problems occurring when students with no interest in a leadership position are given such assignments. The project manager (PM) is responsible for the team's performance and productivity, and the deputy project manager works with the PM and fill in for the PM when necessary. Each team has an assigned CEE faculty mentor who meets the team every week. Each team is supposed to meet at least one hour for each credit hour each week, and the attendance is recorded by the faculty mentor. The faculty mentor monitors the progress of the team to keep them on task, but provides advice and resources based on the request of the team members. If expert advice outside the area of expertise of the faculty mentorr is requested, the faculty member arranges a meeting with an appropriate CEE faculty member to assist the design team. Thus, all CEE faculty members are available to the design teams for consultation, but they have to request for it.

The IDS experience follows a natural progression during the course of the senior year. During the Autumn Quarter, each design team prepares a written proposal including an SOQ (Statement of Qualifications) in response to an RFP (Request for Proposal) from the "client." In addition, at the end of the Autumn Quarter, each team presents a preliminary engineering report on the feasibility of the proposed project. During the Winter Quarter, each team progresses from conceptual ideas to near-final design. During the Sprin*g* Quarter, each team finalizes its proposed design and prepares a detailed cost estimate and bid package for construction. The IDS experience culminates with a formal presentation before an audience of CEE students, faculty mentors, project client, and an advising board of professional engineers. More details of the three distinct, but integrated, phases, I, II, and III, of the course are presented below.

Phase I – Autumn Quarter – Feasibility/Conceptual Planning Phase (CEE 504, 2 credit hours)

The Autumn quarter introduces the class to the concept of an *"integrated,"* or interdisciplinary, type project which is representative of the *real* world. The principal goal of this phase is to develop and hone skills related to oral and written communication of technical ideas, working together productively in teams, encountering and addressing problems and situations that sometimes are "out of the box," group organization, project management, synthesizing existing technical information, and independent learning. Part of the learning experience is how to communicate and work with other disciplines to accomplish a project. The teams visit the project site in the second week at a time when all students are free from other classes. This visit is coordinated with the "client."

In Phase I, each team will prepare a conceptual plan for consideration by the "client." The "client" is a practitioner who identifies the IDS project and defines the deliverables. The "client" also provides all the required information (topographical maps, soil log data, permitting regulations followed by the region, etc.) for the project site or directs the teams to the sources of the information. Each team's conceptual plan will demonstrate how it proposes to *"best"* organize and develop the site to satisfy all client requirements, meet all restrictions and address all regulatory issues, and provide an efficient circulation system to serve traffic movements within as well as to and from the site. The investigation must include the environmental and geotechnical ramifications of the proposed project as well as any drainage, runoff, and erosion issues that might be involved. Also to be included are constructability and structural ramifications. A transportation analysis must address not only circulation on the site, but also its operation within the project site's transportation system. In mid-quarter each team will present a *"proposal"* which shall include:

- The team's understanding of the project.
- The team's proposed approach to conducting the study, i.e., the scope of work.
- The team's schedule, identifying milestones and anticipated mid-term status when a review meeting will be held with the IDS Mentors' Group, and
- The team's estimated "cost," expressed in terms of person-hours, subdivided into major areas or tasks.

Mid-quarter presentation with the "client" and the industry advisory and faculty mentors is essentially a two-way discussion where team members bring in materials (progress reports, challenges encountered, drawings, list of questions, etc.) and initiate a dialogue with the mentors. The outcome provides guidance and support for the students and gives the mentors a basis for evaluating the team's performance at the mid-quarter point.

At the end of the quarter, each team will make a 20 minute PowerPoint presentation to the "client" and the industry advisory and faculty team to demonstrate why and how its conceptual plan is the *"best."* This presentation will be made as "consulting teams" presenting to an audience the results of their work. The presentations should include graphics, some of which would come from the deliverables, and handout material, or "leave-behinds." The purpose of the presentations is to explain to the "public" how the team arrived at its findings and recommendations, what factors were considered in the decision-making process, what alternatives were considered, what the team proposes and why it is the best, and exactly what the team proposes to accomplish in the Winter Quarter (Phase II). The presentations do not go into the technical aspects of the process beyond what is necessary for the audience to understand the final recommendations. The presentation time is limited to allow questions and discussion from the audience, so it is necessary that each team be thoroughly conversant with its work and be able to respond. Each team member must participate in preparing or giving the presentation.

Phase II – Winter Quarter – Design Phase (CEE 505, 3 credit hours)

In Phase II, the design teams will be required to develop the site plans (contours and cross sections), drainage pipes and inlets, roadway plans for all components of the circulation system (plan/profiles, typical sections, intersection geometry and traffic design, and detail elevations for paving), utilities plan (sewer main, water lines, underground electrical, telephone, data, and gas), and right of way and set-back requirements for facilities. Each plan shall also include the significant structural design of a design element, such as a retaining wall, parking deck, small building or major component(s) of larger structures, etc. The plan must also include a cost-effective drainage system to accommodate the ultimate development of the site. "Green Facility" concepts should be considered in the design; drainage must incorporate environmental considerations. The design should promote sustainable waste management by considering options for waste minimization and water re-use. At the end of the quarter, each team will make a 20 minute technical presentation augmented by appropriate handouts and visual aids, and submit a written report to the "client" and the industry advisory and faculty team. Each presentation is followed by a 10 minute question and answers session.

Phase III – Spring Quarter – Bid Package & Final Documents (CEE 506, 1 credit hour)

In Phase III, each design team will add the documentation necessary to transform its plan into a bid document for receipt of proposals from contractors. Documentation will include elements such as specifications, general conditions, definition of bid items, quantities, and estimated construction cost. At the end of the quarter, each team will make a *"final"* 20 minute PowerPoint presentation augmented by appropriate handouts and visual aids oriented toward a non-technical, administrative, and corporate audience showing how the proposed development will best serve users' needs. Each presentation is followed by a 10 minute question and answers session. A written *"final report"* is also required to be submitted to the "client" and the industry advisory and faculty mentors. A suggested outline of the final report is presented in Table I.

TABLE I
SUGGESTED OUTLINE FOR FINAL REPORT

•	Title page with date
•	Cover letter (from team to client)
•	Acknowledgements
•	list all team members, their hometowns, and specific project responsibilities
•	list all engineering consultants, industrial mentors, and CEE faculty mentors
•	Executive summary
•	Table of Contents
•	List of Figures
•	List of Tables
•	List of Notation
1.0	Background
2.0	Project Scope
3.0	Proposed Design
4.0	Preliminary Design
	4.1 Environmental
	4.2 Geotechnical
	4.3 Transportation
	4.4 Structures
	4.5 Water Resources
	4.6 Construction
EACH SECTION WILL INCLUDE:	
4.x1	Field Investigation
4.x2	Data Analysis
4.x3	Findings
4.x4	Design Options (this will include the alternatives not selected and the reasons why they were not chosen)
4.x5	Recommended Option
5.0	Project Cost
6.0	References
7.0	Appendices (if bulky, appendices can be bound as a separate document)
	Drawings, maps, and photos
	Design calculations (each checked by other team members)
	Data from field or other sources
	Other relevant information (regulations/permits)
	Copy of PowerPoint slides

Seminar Series

As part of the IDS course a series of lectures is conducted in the Autumn Quarter on topics intended to guide students in their senior capstone design project and as they approach their transition from student to young engineers beginning a professional career. Expert practitioners, some of whom are part of the IDS industry advisory team, are invited to give one-hour seminars on following topics:

1) Introduction to the IDS Project Selected; 2) Writing Reports and Giving Presentations; 3) Environmental and Permitting Aspects of the Project; 4) Geotechnical Aspects of the Project; 5) Drainage and Erosion Control Aspects; 6) Structural Aspects of the Project; and 7) Construction Aspects of the Project. To augment this seminar series, the seniors also enroll in a separate one credit seminar series course on following topics: 1) Building and Working as Teams; 2) Cost Estimating; 3) Value Engineering; 4) Ethics Issues for Projects' 5) Creativity in Design; 6) Construction Management; 7) Safety and Liability; and 8) Construction Law. For each of these seminars the student prepares a short paper summarizing what he/she experienced from, learned or received from, the presentation. This is a reflective writing and not just a repeat of the material presented in the class.

The seminars in Autumn Quarter reflect the basic disciplines to be addressed in the project – site design, structures, drainage, environmental, geotechnical, transportation, and construction. More detailed lecture series on 1) modeling and related computer software use (HEC-HMS and HEC-RAS) for drainage guidance and 2) preparation of bid package is provided in the Winter Quarter by CEE faculty members, each of two-hour duration. Sessions with the "client" and industry advisory and faculty are scheduled in Autumn, Winter, and Spring Quarters upon request if students are experiencing difficulties.

DESCRIPTION OF THE PROJECT SELECTED

Redevelopment of the Blue Ash Airport, City of Blue Ash

For the 2006-2007 the City of Blue Ash (located about 12 miles from Cincinnati downtown) in collaboration with CDS Associates, Incorporated sponsored the IDS project which focused on the redevelopment of approximately 130 acres of the Blue Ash Airport. The city has procured the Blue Ash Airport and is planning to convert it into a recreational park. The centralized location of the site makes the park easily accessible to the Blue Ash community and the Greater Cincinnati area. Some key elements featured in the design of the park include a performing arts and conference center, a municipal mall with a reflecting pool, an observation tower and bandstand, an "Ultimate Sacrifice" World War II memorial museum including the "My Gal Sal" B-17, and plenty of green space which includes trails, picnic areas, lakes and several gardens, lawn areas and preservation of woodland areas. The park will become a place where people can not only go to enjoy nature, but will furthermore be a place for social and cultural exchange. The project will act as a catalyst for future community development and enhancement within the City of Blue Ash. The five IDS teams working on this project completed their feasibility planning report in December 2006 and presented it to the industry advisors. They completed the designs of their site plan, hydrology and drainage, environmental, structural, geotechnical, transportation, and construction elements in March 2007. The plans are for them to present their whole project including the construction bid package and cost estimate to the City of Blue Ash City Council in May 2007. An aerial view of the Blue Ash airport, and the envisioned redevelopment is shown in Figure 1.

(A) CURRENT AERIAL VIEW OF BLUE ASH AIRPORT

(B) REDEVELOPED IDS PROJECT PLAN ELEMENTS

FIGURE 1
REDEVELOPMENT OF THE BLUE ASH AIRPORT

Previous Projects

The projects selected in the previous years included the following (each project is continued for two years):

- Restoration of the Historic Miami-Whitewater Canal in Cleves, Ohio. This project focused on excavation and preservation of a buried brick arch tunnel, a park, amphitheatre, informal learning center, bicycle and pedestrian routes, picnic areas, and parking.
- Design of Solid Waste Transfer Station for Landfill Operation in Colerain Township, Ohio to reduce the volume of traffic going back to the dumping site by transferring loads from smaller road vehicles into large on-site vehicles, thus reducing lost time for the many road vehicles as well as mud tracked out onto public roads – a festering problem in the community
- Design of the Consolidated Rental Car (CONRAC) Facility for the Greater Cincinnati/Northern Kentucky International Airport to consolidate all rental car companies into one area, each sharing a common building, return lot, fuel farm, but each has its individual storage lot and cleaning facilities. It included a round-trip bus route to move passengers

between the terminals and the CONRAC building, and storm water management for the 60 acre lot.

DESCRIPTION OF THE IDS DESIGN CENTER

In the IDS Design Center each design team has its own office style cubicle with a modern computer that has a full complement of software typically available in a design office in a civil engineering firm. All computers are networked to a high-speed printer (black/white and color) and a plotter that can produce full-size engineering drawings. To assist teams during their planning sessions, the Center also has a conferencing area, with a 50 inch plasma screen Smart-Board. The equipment and software provided in the lab are presented in Figure 2 and Table II.

(A) TYPICAL OFFICE CUBICAL FOR A TEAM

(B) DEDICATED PLOTTER AND PRINTER

FIGURE 2
THE IDS DESIGN CENTER

TABLE II
HARDWARE AND SOFTWARE IN THE IDS DESIGN CENTER

Hardware	Software
• Five High-end Computer Workstations • HP B/W Laserjet Printer • HP Color Printer • HP Large scale Design Plotter • 50-inch Plasma with Smart-Board and multi-media hook-up.	• AUTO-CAD • MICROSTATION • HEC-HMS and HEC-RAS • WaterCAD • MS Office • Wordperfect • Visio • Adobe Acrobat • ArcView GIS

GRADING PROCESS

The grade each quarter is based on a combination of individual performance as well as team performance. As mentioned earlier, each team is supposed to meet at least one hour for each credit hour each week, and the attendance is recorded by the faculty mentor. Thus a portion of the grade is assigned for attendance at these meetings. Quantity as well as quality of work is considered to assess mid-term and final reports. Both team performance assessments and individual performance in the presentations is part of the grade. A rating evaluation form for each team mid-term and final-term presentations is filled by the "client" and the industry advisory and faculty team. A portion of the grade is also based on a peer evaluation where each team member grades the performance of each team member as well as his/her own. Finally, the project management team also evaluates each team member's performance and the faculty mentor assigned to each of the teams also evaluates the project teams. The final report each term is evaluated and graded by each faculty mentor. These evaluations and comments are discussed in a meeting by the faculty mentors and the IDS instructor and a grade is assigned for the final report for each team member (note: each member of a team may or may not receive the same grade). The following grade distribution is used to assign the course grade for the quarter: Attendance = 25%: Peer grading = 10%; Mid-term Team Evaluations = 15%; Presentations = 20%; Team = 10%; Individual = 10%; Team Faculty Mentors' Evaluations = 15%; and Report = 15%

EVALUATIONS AND OUTCOMES

Outcomes and Objectives

For the undergraduate BS CE program at UC the outcomes selected correspond exactly to the program outcomes required by Criterion 3 of U.S. Accreditation Board for Engineering and Technology (ABET) EC 2000 [2]. Explicitly, the graduates of the Civil Engineering Program must demonstrate that they have: (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs; (d) an ability to function in multi-disciplinary teams; (e) an ability to identify, formulate, and solve engineering problems; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global and societal context; (i) a recognition of the need for, and an ability to engage in life-long learning; (j) a knowledge of contemporary issues; and (k) an ability to use techniques, skills, and modern engineering tools necessary for engineering practice.

The principal goal of IDS is to emulate the professional environment where teamwork is essential for collecting and analyzing diverse technical information needed to define and solve contemporary engineering problems. Under this umbrella, IDS has five educational objectives which are cross-listed with program outcomes in Table III. The instruments used to assess IDS outcomes are described in Table IV. Results of assessment tools 2, 3 and 4 listed in Table IV are summarized in Tables V. In each case, the scale is 1 to 5, with 5 being the best. Over the years the assessment process has been developed and implemented in stages. So for certain quarters if the data was not available, it is indicated as NA.

TABLE III
OBJECTIVES & PROGRAM OUTCOMES RELATIONSHIP

IDS Educational Objectives	Outcomes
Engage in continuous independent learning	e, i, j
Work together productively on interdisciplinary teams	d, g
Manage time and resources efficiently to complete a complex project	f, k
Apply technical information to make sound engineering recommendations	a, c, e
Develop and practice effective oral and written communication skills	g, k

TABLE IV
INSTRUMENTS USED TO ASSESS IDS OUTCOMES

No.	Assessment Instrument	ABET Outcomes Addressed	By Whom+	Actions Taken
1	Project review meetings	a, c, e, g	FM, PE, PC	Intervene with design teams, as necessary
2	Team evaluation-(by peer group)	d, f	PG	Intervene with design teams, as necessary
3	Team evaluation (by PM)	d, f	PM	Intervene with design teams, as necessary
4	Student speaker evaluation	a, c, d, e, g, j, k	FM, PE, PC	Modify course delivery and content, as needed
5	Design report evaluation	a, c, d, e, g, j, k	FM, PC	Modify course delivery and content, as needed
6	IDS course evaluation	All	CEE Seniors	Modify course delivery and content, as needed
7	IDS external review	All	PE, PC	Implement suggested improvements
8	Senior exit interview	All	CEE Dept. Head	Modify course delivery and content, as needed.

+ Legend: FM = faculty mentors; PE = professional engineers; PC = project client; PG = peer group (student team members); and PM = project managers (elected student leaders)

IDS External Review

In addition to the quarterly reviews, an external review is also conducted. The external review solicits written feedback from professional engineers who have served on the IDS industry advisory panel and assisted as reviewers. The Professional Engineers judge whether the graduating seniors meet four desired educational outcomes and suggest ways to improve the capstone concept. As a sample, results are presented for the class of 2006 in Table VI.

TABLE V
EVALUATION RESULTS

Team Member Evaluations by Student Project Managers				
Class of	**Fall**	**Winter**	**Spring**	**Size**
2001	4.67	NA	4.62	33
2002	4.55	4.38	NA	32
2003	4.53	4.15	4.50	36
2004	4.07	4.19	NA	35
2005	4.72	5	4.75	40
2006	5	4.55	4.51	38
2007	4.71	4.52	NA	39
Team Member Evaluations by Student Peer Group				
Class of	**Fall**	**Winter**	**Spring**	**Size**
2001	4.66	NA	4.72	33
2002	4.56	4.72	4.74	32
2003	4.58	4.22	4.59	36
2004	4.32	4.59	NA	35
2005	4.44	4.53	4.73	40
2006	4.64	4.74	4.92	38
2007	4.65	4.58	NA	39
Speaker Evaluations by Faculty Mentors and PE Advisors				
Class of	**Fall**	**Winter**	**Spring**	**Size**
2001	4.75	3.63	4.85	33
2002	4.41	4.40	NA	32
2003	4.58	NA	4.60	36
2004	4.50	4.12	NA	35
2005	4.34	4.72	4.52	40
2006	4.38	4.40	4.59	38
2007	4.33	4.35	NA	39

TABLE VI
ASSESSMENT OF EDUCATIONAL OUTCOMES OF CLASS OF 2006 BY EXTERNAL REVIEW PANEL OF 8 PRACTITIONERS

Rating+	Outcomes Achieved by CEE Graduates
4.57	The student team demonstrated that they understood the pertinent economic and sustainability issues that need to be considered for the project.
4.43	The student team demonstrated that they had a clear understanding of the pertinent environmental and health and safety issues that need to be considered for the project.
4.29	The student team demonstrated that they had a clear understanding of the pertinent ethical, social, and political issues that need to be considered for the project.
4.86	The student team has presented a practical constructible solution to the problem.

+ Note: 5 – strongly agree; 4 – agree; 3 – neutral; 2 – disagree; and 1 – strongly disagree

CONCLUDING REMARKS

The Integrated Design Sequence for the CE Senior Class at University of Cincinnati occupies a unique niche in the CEE curriculum. Since its inception in Autumn 2000, IDS has been quite successful in introducing Civil and Environmental Engineering Seniors to a realistic open-ended design experience where teamwork, planning, and ingenuity are critical for defining and solving a contemporary engineering problem.

REFERENCES

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