The Senior Design Process at Purdue University

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Abstract

This paper examines the participation of practitioners in senior design based on experience at Purdue University where senior design involves all seniors in their last semester before graduation and is titled "Civil Engineering Design Project". It is described in the catalog as "Planning, design, and analysis of a civil project; an integrated and realistic group project involving as much as possible all major aspects of the civil engineering profession." This high enrollment course (30 to 100 students per semester) has been taught since the early 1960's and there have been many approaches to teaching it. Involvement of practitioners has varied from nearly no involvement through nearly total responsibility for the course. The author has observed the teaching of this course for thirteen years and has the lead responsibility for the course in the spring semester for the past four years. The paper describes the course and approaches to teaching it and will summarize observations of what worked well and what did not work well regarding the involvement of practitioners. Recommendations are made for effective use of practitioners in senior design.

Introduction and Background on Senior Design

The capstone design course in Civil Engineering at Purdue University, CE498 has been ongoing since 1960. Drnevich[1] provided the evolution of this course from 1960 to 2001. A summary of these will be provided herein. Table 1 lists the projects designed in this course. Perusal of the table indicates significant diversity of project types. Most of the projects are real in the sense that they were either in consideration or in process at the time that they were being designed in the course. Students worked with actual project information and generally had to diligently search to obtain that information. Design products of the course were not used in the actual construction, but in many cases had an influence on actual designs. This occurred because persons actually involved in the real projects almost always participated in the course. Hence, the definition of "practitioner" associated with this course is a broad one that includes:

1. Practicing engineers who are engaged in the design of the actual or similar projects;
2. Contractors who have to estimate, bid on, and build the actual or similar projects;
3. Owners (or owner's representatives such as engineers in Purdue's Physical Facilities Department and the Indiana Department of Transportation);
4. Users of the projects who critique functionality and serviceability of the facility;
5. Engineers who represent vendors and associations of engineered products and design software;
6. Professionals associated with human resource, finance, marketing, and business issues;
7. Public officials who represent the community's perspective; and
8. The Civil Engineering Advisory Council members who periodically review the course.

Table 1. Listing of Capstone Design Projects at Purdue

1960	Candy Factory	1961	Tippecanoe Co Airport Retention Reservoir	1962	Research Park/Residential Purdue Parking Problem	1963	Belt Line Railroad Tricounty Airport
1964	Purdue Research Bldg Wabash Channel Imp.	1965	Continuing Education Fac. Lafayette Industrial Pk.	1966	Reclamation Gravel Pit 1985 Campus Master Plan	1967	Wildcat Ck. Res. Housing Indy-Chicago Trans. Corridor
1968	Wholesale Warehouse Lafayette Urban Redevelopment	1969	Purdue Airport Tower Safety Rest Area	1970	Pre-stressed Concrete Plant Race track	1971	Local By Pass Camp Talitha
1972	Local by-pass Road Camp Talitha	1973	Wildlife Park Winter Recreation Site	1974	Central States Power Plant Wabash River Channelization	1975	Riverfront Park Tri City Airport
1976	Hog Abattoir Shopping Center	1977	Local Subdiv. Park Cluster Housing Cumberland	1978	Caterpillar Industrial Park Auto Race Track	1979	Retirement Health Center Master Plan Happy Hollow
1980	Master Plan IV Tech W.L. Park/ Community Ctr.	1981	Waste Energy Generation Plant Sagamore Regional Shopping	1982	Lafayette Elks Subdivision Tippecanoe State Park	1983	Local Expressway Animal Science Center
1984	Animal Science Center Local by-pass	1985	Recreational Facility Dairy Farm Happy Hollow Park	1986	Purdue Master Plan Wabash River Renovation	1987	Tippecanoe Trash Transfer Station Florida Underwater Habitat
1988	Salisbury Community Park 5 County Incinerator	1989	Tippecanoe Truck Stop Arlington Race Track	1990	Heliport/ National Guard Landfill/Incinerator	1991	Wastewater Plant for WL Recreational Complex
1992	Regional Airport Recreation/ Convention Ctr.	1993	High Speed Rail Corridor Wetlands Viewing Center	1994	Food Science Ed. Building Retirement facility	1995	Purdue Airport Terminal and Runway Exp. Landfill Remediation
1996	Incinerator for Mid Indiana. Research Park including Hdqtrs Building	1997	Site and Design Grocery Store Agronomy Research Center	1998	Aquatic Center	1999	Visual & Performing Arts Center Extension of U.S.231
2000	Diamond Interchange at I65/SR26 SR 26 and US-52 Improvement	2001	High Performance, Large Scale laboratory Reworking Mackey Arena	2002	New Purdue Airport Terminal Facility Alternates for Mackey Arena	2003	Bowen Civil Engineering Lab Expansion of Mackey Arena
2004	US 231 Relocation Eval. of Mackey Arena Proposals	2005	Menards Home Supply Mega Store				

In a typical semester, it is not unusual for ten or more "practitioners" to be involved in the course. The nature of the involvement may range from presentation of a technical session to participation as a reviewer and critique in the sessions where the student teams make their formal presentations.

Course Details - The course is taught every semester and is limited only to seniors in their last semester before graduation. This requirement allows for having a more complete preparation for taking this course. Class sizes have ranged from a low of about 25 students to more than 110 (with 22 teams). Students are formed in teams of five persons, but sometimes teams of four or six persons are allowed, depending on the total number of students in the class. Originally, and until recently, each student on a team represented a civil engineering subspecialty. Typically, there would be a structural person, a geotechnical person, a environmental/hydraulics person, an environmental person, a construction person, and a transportation person. The assignment of these subspecialty responsibilities was based on student interest, elective courses taken, and occasionally, expediency. Frequently, students were assigned to areas outside those of their interest or where they only had a basic level course. These students were challenged to become productive team members.

Typically, the course has three to five faculty persons assigned each semester with one faculty person having the role of lead instructor. The faculty persons assigned are from the various subspecialties listed above. Additionally, there are three to five teaching assistants assigned to the course, again from the subspecialties. The faculty and teaching assistants constitute the "instructional staff" for the course. They participate in the planning of the course through weekly staff sessions, attend all of the technical sessions of the course, give some of the technical presentations, and are engaged in grading of the presentations and products.

Course Objectives - While objectives for this course were clearly established by the faculty who founded and taught the course over the years, with the advent of Engineering Criteria 2000[2], our faculty updated the course objectives in the mid 1990s:

By the end of this course, the student will be able to:

1. *Integrate the technical sub-disciplines of civil engineering, develop criteria for design and perform trade-off and alternatives analyses to produce cost-effective solutions.*
2. *Gather relevant data, have discussions with the client, identify and use applicable regulations, codes and other information.*
3. *Communicate site analyses, work programs and engineering design detail to both technical and non-technical customers.*
4. *Do integrated project planning, scheduling, and cost analysis for a moderately-sized, civil engineering project.*
5. *Perform a reasonably detailed design to meet customer requirements using, where appropriate, software and computer techniques to satisfy design objectives and to prepare requested construction documentation.*
6. *Experience the benefits and applicability of multi-disciplinary teams to achieve successful project completion.*

Myers-Briggs Type Indicator in Team Formation - Starting in the mid 1990's, course lead instructor Robert Whitford began having the students take the Myers-Briggs Type Indicator[3] (MBTI) test. The MBTI identifies personality types by use of four letters, E or I, S or N, T or F, J or P as described in Table 2. The test was scored and a qualified MBTI person was invited to a class session to interpret the test and help students and instructors gain a better understanding of and respect for personality differences. The instructional staff frequently makes use of the MBTI of team members along with advice from the qualified MBTI person in resolving disputes and poor performance of teams and/or members of a team.

Table 2. Myers-Briggs Type Indicator Categories and Descriptions

Type	Symbol	Description
EXTROVERTS	E	Try things out, focus on the outer world of people
INTROVERTS	I	Think things through, focus on the inner world of ideas and impressions
SENSORS	S	Practical detail-oriented, focus on the concrete information, facts and procedures gained from their senses
INTUITORS	N	Imaginative, concept-oriented, focus on meanings and future, with a view towards patterns and possibilities
THINKERS	T	Skeptical, tend to make decisions based on logic, rules and on objective analysis of cause and effect
FEELERS	F	Appreciative, tend to make decisions based on values, personal and humanistic considerations, and subjective evaluation of person-centered concerns
JUDGERS	J	Set and follow agendas, planned and organized approach to life and prefer to have things settled, seek closure even with incomplete data
PERCEIVERS	P	Adapt to changing circumstances, flexible and spontaneous resist closure to obtain more data

The instructors make use of this information along with grade point average and elective course history in forming the teams. It is interesting that about 60 percent of the class can be typed as introverts and the most common type is Introvert, Sensor, Thinker, Judger, (ISTJ).

Site Visits and Architectural Conceptual Drawings - Students generally have a difficult time visualizing what the completed facility will look like and how the design of selected components affects the overall facility. Efforts are made to get students to visit the site of the project and or sites of similar projects. Where buildings are concerned, an effort is made to obtain architectural schematic drawings for the facility or for similar facilities to assist the students in forming better images of the project.

Changing Focus from Subspecialties to Broader Perspective - The author experimented in the last four spring sessions of teaching the course by broadening the focus and responsibilities for all the students. With the past focus on the subspecialties in the Civil Engineering program at Purdue, instructors noted a tendency for students to only do the work in their subspecialty and not contribute to the work in other areas. Since work across the subspecialties is not evenly distributed in most projects, some students were greatly overloaded while others enjoyed a relatively light load. Since the spring 2001 session, no assignments to subspecialties were made and lectures associated with subspecialty topics were presented to the entire class. Students were advised that everyone in the team had responsibility for responding to the Request for Qualifications (*RFQ*) and Request for Proposals (*RFP*) and that the formal checking process would require that they develop competence in several, if not all areas needed to meet project objectives and deadlines. It was explained to them that their degree was in civil engineering and not in a subspecialty and that it was quite likely that each would have to work in a variety of subspecialties or at least work with people in other subspecialties as their careers progressed. Furthermore, people with the broader vision were more likely to advance to leadership positions. This approach appears to have been appreciated by at least some of the students (typically the better ones) and there was more widespread ownership of the work, i.e. increased teamwork.

Use of the Web for all Course Materials and Products - The worldwide web also is becoming an increasingly important component to the teaching, design, and construction processes. In the mid-1990's, instructors of this course began using the web for course information so that students could get ready access to this information. In Spring 2001, the author with the assistance of his co-instructors David Harmelink and Robert Frosch made exclusive use of WebCT (**http://www.webct.com/**), a course authoring system adopted by Purdue University. This greatly expanded the use of the web while restricting access to only the instructional staff and students. Figure 1 is a copy of the course home page. It not only provides course information (syllabus, calendar, lecture notes, references, etc.), but it is a communication tool between the

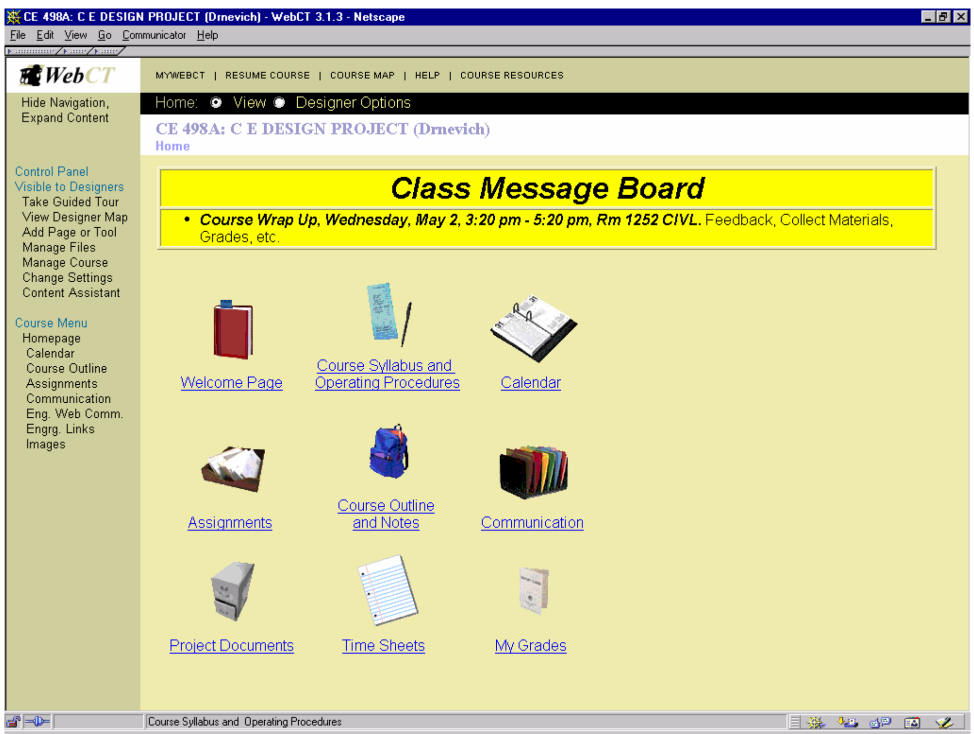

Fig. 1. Home Page for CE498 at Purdue University (Access limited to Instructional Staff and Enrolled Students)

students, members of their teams, and the course faculty and staff. The Communication page is shown in Fig. 2. The Contacts part of the communication feature was exceptionally helpful because it contains the team names, photos of the teams, listing of team members, team e-mail address, and individual phone numbers and e-mail addresses. We also generated a link from the individual student to that student's resume. With a large class size, this help tremendously in getting to know the students as individuals.

One of the most difficult aspects of team-based courses is access by all team members and instructors to the team products and deliverables. The *Presentations* link provided a location for each team to post all of their products including reports, presentations, drawings, and calculations. Virtually all types of files may be stored including word processing documents, spreadsheets, presentation slides, photograph files, scheduling documents and charts, and drawings. All are stored in their original form. Hence, members of a team can keep their work in progress stored here and others on the team (and the instructors) can access any item, work on it, and save it from anywhere the person has access to the Internet, twenty four hours a day, seven days a week.

WebCT was helpful in having the students report their work hours through the *Timesheet* link and for each student to get an up-to-date listing of his/her progress in the course through the *My Grades* link. WebCT allows for easy posting of grades and will automatically calculate the overall grades, including assigning letter grades according to criteria established by the instructor. Drnevich[4] gives additional information on the use of WebCT in teaching another civil engineering course.

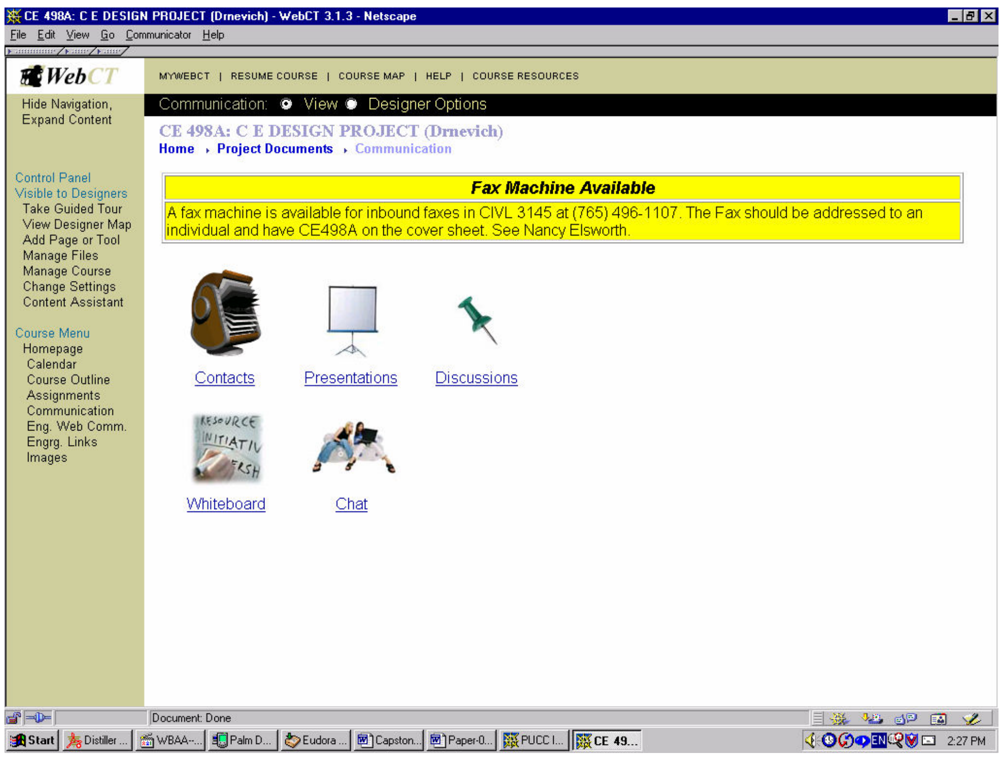

Fig. 2. The Communications Page for CE 498 at Purdue University

Design-Build - In the Spring 2001, the instructors used the Design-Build approach in place of the Design-Bid-Build approach. The course was conducted in two phases: Phase I: Request for Qualifications and Phase II: Request for Proposals. Student teams had to generate an identity and history for their firms and provide a written statement of qualifications and make oral presentation before becoming eligible to receive the Request for Proposals (*RFQ*). For Phase II, the Request for Proposals (*RFP*) and associated addenda set the criteria for the products and deliverables in this phase. The *RFP* was crafted with the assistance of a practicing professional, Robert Law, an alumnus who is the chief estimator for Pankow Builders, Ltd., a firm founded by another alumnus, Charles Pankow, and which has specialized in design-build work for more than

30 years. Mr. Law was given access to the course through a fictitious student and could monitor course progress and provide advice to the faculty and students from his west coast office. He also made several visits to the class during the semester and sat as one of the panelists for some of the presentations.

Professionalism and Ethics - Rather than the traditional student-teacher relationship, the approach taken since the spring 2001 semester was a professional one. For all activities except the presentations, the course instructors played the role of *principals* in the *firm*. The teaching assistants played the role of *engineering managers.* The students were then the *design engineers.* For the presentations, the students then took on the role of *principals of their firms* while the instructors joined others from engineering practice in the role of *owners and clients*.

At the outset of the course, references were made to the *Codes of Ethics* of the *American Society of Civil Engineers*[4] and of the *National Society for Professional Engineers*[5] as guides for activities and relationships in the conduct of this course. The relationships among design professionals and between them and their clients were addressed through several assignments from the course text *Quality in the Constructed Project: A Guide for Owners, Designers, and Contactors*[6]. Several of the in-class sessions discussed these relationships and the roles of professionals. The presentations and discussions led by practicing professionals are especially effective.

Assessment

Students in past years generally disliked this course while they were taking it because it was so different from other courses that they had taken and it entailed so much work. However, a survey of alumni done in 1995 indicated that it was among the best courses that they had taken. From the spring 2001 offering of the course as, a mid-term request for feedback provided generally favorable comments and some helpful suggestions that were frequently implemented, if not immediately, for the following offering of the course. The course and instructor evaluations at the end of the semester were quite positive. A number of the students suggested that too much time was spent on the early part of the course and responding to the *RFQ* leaving insufficient time for doing the design work and responding to the *RFP.* This suggestion guided the course calendar for subsequent times the author teaches the course. However, there never seems to be sufficient time available in the course, which is a typical situation in engineering practice. Additional surveys of alumni five years after graduation are underway at the time of this writing.

In the spring of 2004, the Civil Engineering Advisory Council, which consists of 15 practitioners and five faculty persons, were charged with reviewing senior design and making nearly unconstrained recommendations to the faculty for how the School of Civil Engineering can best prepare students for their futures, whether they be in engineering practice, graduate school, or other careers. The constraints placed on the Council were that the program had to meet ABET *EC2000 Accreditation Criteria*[2] and resources for accomplishing the design component were within reason. The Council took this charge seriously and conducted interviews with: project "owners" such as the Purdue Athletic Director (for the Mackey Arena projects), the course instructors and other faculty, with recent graduates of the program, and with students currently taking the course. In the fall of 2004, the Council provided a written report[8] to the

School Head with its findings and recommendations. Recommendations are excerpted below from the report:

Without equivocation, each and every CEAC member present [for the review] *affirmed the importance and benefit of senior design for the student, faculty and industry.*

These [Advisory Council] *members place a priority in their hiring and promotion efforts to seek (and retain) skilled individuals who have demonstrated skills in leadership and team work. Successful Civil Engineering enterprises and projects are the direct result of strong leaders and empowered project teams. This is the future of Civil Engineering. Purdue's Civil Engineering course CE 498 (senior design) helps prepare Purdue's students for a dynamic and rewarding profession.*

Specific recommendations of the Council included:

1. *Affirm Value of CE 498*
   - *Keep CE 498*
   - *This course offers an outstanding opportunity to combine a diverse body of undergraduate course work into a single/unified class, building teamwork and achieving creative design solutions.*
2. *Applaud CE 498*
   - *This course offers "Real World" and practical training in team building, searching for solutions with realistic schedule/budget pressures.*
   - *The course reinforces communication skills, report preparation and plan production.*
3. *Support CE 498*
   - *Increase the course's credit value from three (3) to five (5) credit hours. This would reinforce the course's merit and acknowledge the effort required by the student, both in class and personal, to successfully complete the course.*
   - *Offer the faculty a premium and/or bonus for organizing, teaching and participating in this course.*
4. *Course Title - Change the name of CE 498 from "Senior Design" To "The Project Delivery Process."*
5. *Improve CE 498*
   - *Build/assign better project teams: Revise grouping to ensure that each group has adequate representation of the major sub-disciplines*
   - *Use Myers Brigg Evaluation in the team member selection process*
   - *Incorporate/Distribute Co-OP/Internship students on the various teams*
6. *Enhance skill sets*
   - *At the beginning of the course, have each student complete an experience questionnaire. Questions should include the level of auto CADD experience, Power Point skills, word processing ability, use of spreadsheets, etc. to ascertain each team member's abilities.*
   - *Use this information to better balance and establish the design teams.*
7. *Promote team compatibility through extra curricular activities*

8. *Utilize Project Mentors*
    - *Utilize Project Message Board*
    - *Invite Professional Mentors – Have biweekly presentations*
    - *Promote Interaction – Establish a "Go To" person to provide students with uniform and consistent answers*
9. *Establish feedback opportunities by both senior students and professionals*
    - *Develop a Team Building Concept earlier in the 4 Year Program*
    - *Provide an overview of specialty areas in the field of Civil Engineering*
    - *Emphasize Team Building*
    - *Establish feedback mechanisms where students, professionals and faculty teaching the course can participate.*
10. *Provide Adequate Resources for Success*
    - *Assign strong faculty leaders to manage and teach CE 498*
    - *Provide financial support for field trips and other benefits*
11. *Make CE 498 the envy of all engineering students at Purdue.*
12. *Maintain Project Selections*
    - *Projects should continue to be "Real World" based*
    - *Incorporate all major sub disciplines in the project process*
    - *Retain horizontal instead of vertical focus*
    - *Select and define projects which create work for each team member*
13. *Continue to profess the concept of the Project Delivery Process*
14. *Be positive and show excitement in conducting the course*
    - *Always present a positive "can-do-this" attitude to the course participants.*
15. *As much as possible, offer opportunities for the students to meet and interact with the actual end users of the course's project.*
16. *Develop a project debriefing as part of the course including:*
    - *Do's*
    - *Don't's*
    - *Lessons Learned*

In summary, the CEAC members who were present and participated in this evaluation of CE 498 wholeheartedly recommend that the course remain in the Civil Engineering Curriculum. The course brings together a body of knowledge that the students have gained in their undergraduate course work and engages them in delivering a real world project. The insight that the Council gained during this evaluation enabled us to formulate and recommend suggestions on how the course can be improved to provide an even higher-level of reward for all involved in its teaching and learning.

Making Effective Use of Practitioners

Few practitioners are skilled as educators and few educators are actively practicing civil engineering. Involving practitioners in design courses presents an opportunity for faculty to enhance their understanding of engineering practice issues if they actively participate in the sessions with the practitioners. Since few practitioners are skilled in the art of teaching, educators should work with them in preparing for presentations and handout materials.

Expertise of practitioners can be very helpful in designing the course itself and in key components of the course such as *RFQs* and *RFPs*. Practitioners can be especially effective in listening to student presentations, engaging them with questions, and providing feedback on both the positive aspects and shortcomings of their designs and presentations.

Students don't get much information on career topics such as performance evaluations, advancement, interaction with colleagues and clients. Practitioners involved with Human Resources can be especially helpful in this arena. They also can be helpful to the course instructors with resolving individual and team performance issues. The Myers-Briggs information is very useful in these situations.

Summary and Conclusions

The senior capstone design course in Civil Engineering at Purdue University has a long history of preparing students for engineering practice. Some recent changes include migrating to a closed, Web-based system, broadening the role of the individual student, and making use of newer contract delivery methods such as *design-build.* All of these changes seem to be beneficial to the learning process and the building of teamwork. They also will prepare the student to better enter the profession of civil engineering.

This course is truly the signature course of the Civil Engineering Program at Purdue, but it is very resource intensive and requires significant time and effort to successfully conduct. In the university, the demands for financial resources seem to be at all-time highs and pressures are on faculty persons to spend their time in ways that support their tenure, promotion, and stature. For the past decade, this capstone design course has been continually evaluated with the notion that it could be replaced with a less resource intensive course (or with subspecialty design courses that are easier to teach) that would still satisfy accreditation requirements. In 2004 the Civil Engineering Advisory Council reviewed senior design at Purdue, strongly endorsed the course, and made numerous recommendations for improving it. Many of their recommendations are now being incorporated into the course.

Acknowledgements

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BIBLIOGRAPHIC INFORMATION

1. Drnevich, V.P., (2001). Evolution of the CE Capstone Design Course at Purdue, ASCE Education Congress, Houston, Texas.

2. ABET (2000). Engineering Criteria 2000, Accreditation Board for Engineering and Technology, 111 Market Pl., Suite 1050, Baltimore, MD 21202, Phone: (410) 347-7700. (http://www.abet.org/eac.html)

3. Meyers-Briggs (2000). Myers-Briggs Type Indicator, Consulting Psychologies Press, Inc., 3803 E. Bayshore Road, Palo Alto, California 94303.

4. Drnevich, V. P., (2001). "A Case Study of Using the Web to Teach Civil Engineering Ethics, Professionalism and History," Proceedings of the Annual Meeting of the American Society for Engineering Education, June, 11p.

5. ASCE Code of Ethics, http://www.asce.org/professional/ethics/

6. NSPE Code of Ethics, http://www.nspe.org/ethics/eh1-codepage.asp

7. ASCE (2000). Quality in the Constructed Project: A Guide for Owners, Designers, and Contactors (2000), 2nd Edition, (Manuals and reports of engineering practice), American Society of Civil Engineers, Reston, Virginia, 2000, 266p.

8. Unpublished Letter Report to Fred Mannering, Head, School of Civil Engineering, Purdue University, July, 2004.

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