Teaching the Capstone Course Using Interdisciplinary Student Teams

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Construction project delivery methods are changing; integrated project delivery systems are becoming more and more prevalent in the industry. Most programs of construction higher education offer a senior capstone course designed to require students to integrate previous coursework into a comprehensive, team-based course to better prepare them for initial industry employment. Capstone courses typically have some industry involvement to promote realism and to insure that contemporary construction issues are introduced. This paper is a case study of a capstone course taught at the author's university with emphasis on the creation of interdisciplinary teams pursuing integrated project delivery with industry sponsor involvement.

Keywords: Capstone Course, Industry Sponsor, Team-based Learning, Interdisciplinary, Integrated Project Delivery

Introduction

With the evolution of multiple project delivery systems, like CM at Risk [CMR], design-build [DB], and a myriad of hybrid delivery methods, constructors are finding themselves more and more involved with designers earlier in the project delivery process. Builders are being teamed with designers to facilitate design tradeoffs on materials and methods of construction and to act as the budget watchdog for the owner. This interdisciplinary teaming relationship may be in the form of a builder's preconstruction services provided to the owner as the design process is executed, or in a contractual design-build relationship where the designer may be a subcontractor to the builder. Future builders need to have an appreciation for the entire project delivery process and be prepared to work in an interdisciplinary team environment, often taking a leadership role.

Most programs of construction higher education offer a senior capstone course, designed to integrate previous coursework into a comprehensive, team-based course to better prepare students for initial industry employment. As implied by the name "capstone", these courses should be rigorous, all-encompassing, and focused on real, contemporary construction issues. At the author's university, capstone courses are offered in multiple industry sectors—residential, interdisciplinary, commercial, heavy-highway and industrial; students can select their desired capstone course depending on the sector of the industry they intend to enter. The focus of this paper is on the interdisciplinary capstone course, but the principles of interdisciplinary teaming can be applied to the other sector capstone courses as well. In a previous paper, the author presented the case for involving an industry sponsor with a capstone course (Smith, 2007). The premises in that paper, suggesting that industry sponsorship had multiple benefits to the capstone class, may be enhanced if another dimension is added, the creation of interdisciplinary student teams.

Literature Review

The literature is replete with publications discussing the use of industry in capstone courses. Arthur Kney and his colleagues at Lafayette College discuss the process of developing a set of defined goals and objectives of a capstone course and how those goals may be achieved (Kney, 2003). Others have suggested that capstone courses should be team-taught with appropriate faculty expertise focusing on different learning objectives (Jones, et al, 2007). The cadets at West Point, who are senior CE majors, work on real projects furnished by the construction and engineering industries (Welch, et al, 2005). An excellent discussion of the methods and techniques to evaluate student capstone work and a means for course assessment are provided by Charles McIntyre from North Dakota State University (McIntyre, 2003). The **References** page contains some of the best resources found by the author.

The Concept

The fundamental concepts of creating an interdisciplinary capstone course are:

- Select two or more senior classes of different disciplines and have them collaborate on a common project,
- Create interdisciplinary student teams to accomplish the project,
- Find or create a project that uses the work product from all disciplines, yet requires collaboration between the disciplines.

A Case Study

The case study used in this paper was executed at the author's university in the spring of 2008. There were two classes involved, a senior Construction Science Interdisciplinary capstone course and a senior [4th year] architecture studio. An industry sponsor collaborated with the project, serving the role of owner's representative and subject matter expert for selected topics [such as conceptual estimating] where they provided guest lectures.

Instructor Partnering

One of the challenges in conducting an interdisciplinary class is to find compatible instructors who appreciate the value of interdisciplinary work and understand the intricacies involved. In this case, the architecture instructor was a design-builder and was eager to have his students work in interdisciplinary teams.

It is essential for the instructors involved to have compatible syllabi and schedules and extensive coordination needs to take place well before the start of the semester. Sometimes the class will meet together; sometimes the classes will meet separately, and once the teams are formed much of the student's time is devoted to team work sessions.

In the case of both classes, the interdisciplinary team project was not the only requirement for each class. The Construction Science students had an individual research/writing project and examinations on project delivery systems taken from the assigned texts and lectures. The design students had an individual design project which the instructor required be completed in the first four weeks of the semester. Each instructor graded his own students with the team project accounting for a large portion of the final grade. For the Construction Science students, the team project accounted for 50% of their overall grade.

The Class Project

The project used for this case was a design-build project for a religious facility. A Request For Proposal [RFP] was written by the instructors, patterned after an RFP for a school design-build project and designed to challenge the teams across the gamut of current issues. A copy of that RFP is at the Appendix. Very limited performance requirements were included in the RFP and student teams had wide flexibility in preparing their proposal. To enrich the learning process, student teams were permitted to choose the religious denominations they would design for, and each team was given a different county in the State of Texas as their building site. Most teams picked a Christian religion; two teams picked a non-Christian religion. Locating them in different counties required the teams to research the counties for weather, soil conditions, codes, permits required, etc.

Creating the Teams

The instructors created the teams essentially arbitrarily; with limited exposure to the students after four weeks, the instructors sought to balance team capabilities to the extent possible. Eight student teams were created with four or five students per team. Each team had at least two designers and two builders. Teams were created about the fourth week in the semester and the RFP was provided to the teams at that time.

Team Deliverables

The team deliverables are spelled out in the RFP. Constant emphasis was placed on the concept that the teams were to act as competitors for the project and they had to convince the owner that they had the best proposal. The "owner's representatives" would review and critique the written and oral proposals, ultimately selecting the best proposal to receive the contract award. In this case, the "owner's representatives" were representatives from the industry sponsor who had agreed to review and rank the written proposals and to hear and rank the oral presentations, and finally select the overall best proposal.

Teaming Agreement

Immediately after forming the student teams, the teams had to respond to a teaming exercise in an effort to encourage them to get organized and functioning as soon as possible. This exercise served its intended purpose for most teams; some did not take it seriously initially.

Mid-point review

Most RFPs will have some sort of pre-proposal conference and we revised this pre-proposal conference into a mid-point review. The review requirements were provided to the teams as an addendum to the RFP. This review was a team "pin-up" with teams displaying their work in progress, including schematic design, preliminary estimate, schedule and material trade-offs. These pin-ups were reviewed by the industry sponsor "owner's representatives" and by other faculty, and teams were given feedback/critique of their evolving work product. The mid-point review was scheduled about five weeks after they received the RFP.

Written Proposal

The written proposal requirements were spelled out in the RFP. The teams received guest lectures from the industry sponsor on proposal preparation and professional presentations. Written proposals were due per the RFP at a date/time certain. Late proposals lost one point for each minute they were late. Two proposals were late with the worst case losing 22 points, but most were on time and in accordance with the RFP requirements. Sufficient copies were received to provide copies to the instructors and three copies to the industry sponsor. Three representatives of the industry sponsor critically reviewed the proposals, marked them up highlighting problem areas, and ranked them from 1-8.

Oral Presentations

Requirements for oral team presentations were specified in another Addendum to the RFP. All eight teams presented on the same day immediately following the last day of class. The oral presentations were juried by the same three industry representatives who had reviewed the written proposals. Again, they provided instant analysis and feedback to the teams in the Q&A sessions, and they scored each presentation and ranked them all from 1-8. A social event followed the last presentation and the industry sponsor group conducted a post mortem and provided some prizes for the best teams.

Grading and Critique

Each instructor graded their own class in accordance with the respective syllabi. The team project accounted for 50% of their overall course grade. The written proposal accounted for 25% and the oral presentation accounted for 25%. For both the written and oral proposals a grading protocol sheet was prepared and used by the instructor to score the team work product. The grading protocol gave consideration to the industry sponsor critique and ranking, but the instructor independently graded each team work product. For example, in grading the written proposal, the owner's ranking accounted for 30% of the grade of that assignment; the team ranked Number 1 received the full 30% and lower ranked teams received progressively lower scores. The remaining 70% of the grade was determined by the instructor, considering format, grammar and content. Once a team grade was determined, each team member received that same grade. For the future consideration is being given to integrating some form of peer review.

Student Benefits

Maintaining student interest and focus in their last semester is often a challenge. Creating interdisciplinary teams and setting up competition between those teams helps capture the students' interest. Active involvement of an industry sponsor also helps to heighten the students' interest and brings credibility to the learning objectives and the learning process. Students relate to practicing professionals, particularly if the coursework involves concepts and tasks that they will face early in their careers. Involving the industry sponsor in the evaluation process also enhances the sense of competition among the student teams, which causes them to seek excellence in their required coursework.

In this particular case, the team members learned from each other. The construction students had very limited understanding of the design delivery process, and the design students had no exposure to working with a budget and looking at material tradeoffs. Neither had worked in a competitive environment where they were competing to "win a contract". Many requirements of the RFP, like the LEED's analysis, were completely new to the entire team. Initially there is serious confrontation among team members which quickly disappears as they begin to appreciate the contributions of all. Team leadership usually "breaks out"—sometimes a designer becomes the team leader, sometimes a builder takes the lead. They quickly come to the realization that they must work together, they must discipline themselves to communicate and work against a schedule, and they must each carry a portion of the team load.

Sponsor Benefits

Why should a construction company be willing to undertake the industry sponsor role, committing significant time and resources to support the course? While some benefits are fairly obvious, others are more subtle:

- Company name recognition. Companies are continuing to compete for new entry-level construction managers and the visibility inherent in sponsorship is attractive to companies. This visibility can be enhanced with internet and hard copy postings that feature the company's role.
- Professional pride/industry service. Participating companies view this sponsorship role as a laudable service contribution by the company to the university and the program. Most companies pride themselves in supporting their communities with visible service activities, and course sponsorship certainly contributes to that goal.
- Guest speaker skills enhancement. Most companies promote continuing education for its employees, to include the enhancement of presentation skills for key employees who represent to company in owner presentations and other public forums. Companies can use the guest speaker opportunities to improve the guest speaker's presentation skills; an informal speaker evaluation form may be used to let the students evaluate the speaker's visuals and presentation. In one instance a sponsoring company instituted a 'competition' among its guest speakers, using the student evaluations to rank guest speakers.

Instructor/Program Benefits

Creating interdisciplinary student teams and using an industry sponsor complicates the course delivery for the instructors. The instructors must be flexible and be prepared for schedule changes and modifications. Murphy's Law will apply and the instructors must have alternate plans. If a guest speaker cancels at the last minute, the instructors must be prepared to deliver the same material or have a substitute topic. If key company participants change, new participants must be found and read in. Given these inevitable complications, participation by an industry sponsor with interdisciplinary student teams insures that—

- Student engagement. Creating interdisciplinary teams with an industry sponsor, who will have some influence on their grade, helps engage the students. Creating student teams and the competition provided by industry reviews of their teamwork, gets students competitive juices flowing and keeps them focused throughout the semester.
- Currency. Using an industry sponsor and a current project RFQ/RFP, which can be tailored for teaching purposes, insures that the students *and the instructor* are focused on current issues, practices and procedures.
- Relevance. The course becomes relevant as the students experience the 'real world' which awaits them as they join the industry. The students experience roles that they will be expected to play shortly following graduation.
- Program visibility. In all likelihood, the sponsoring company will be a member of the program's industry advisory council. The company will gain new insight and respect for the program's goals and objectives and what is involved in preparing students to enter the industry. Sponsoring companies will become even stronger program advocates and will be even more willing to support the program with time and resources.

Other Interdisciplinary Capstone Options

There are many options available to programs to seek interdisciplinary team capstone experiences. A few examples from the author's experience:

- Low level nuclear waste storage facility. Teams consisted of designers, builders, and nuclear engineering students who provided "expert" consulting as to the nuclear requirements.
- Highway project. Teams consisted of builders and designers [Civil Engineering students] required to bid a real project at a highway letting, and also to select and justify the pavement structure [asphaltic concrete versus concrete].

- Study abroad facility, Costa Rica. Graduate students in construction, design and landscape architecture were formed into teams to prepare a proposal for an educational facility, including housing, in a Costa Rican rain forest.
- Forest Service research facility. In addition to design and construction students, teams included LEED "expert consultants" from a third class on green building. LEED certification was a major element of the team RFP.

The teaming options are almost unlimited and up to the imagination of the faculty. In the author's experience collaboration of three classes stretches the ability of the instructors to coordinate and evaluate the team work product. It is often more difficult to find faculty who are willing to discard their normal syllabus and agree to use interdisciplinary student teams as the teaching vehicle; it does involve more time and energy on the faculty member's part.

Summary

The construction industry is moving toward integrated project delivery. Historically academia has fostered "stovepipe" learning with designers and builders in separate disciplines. The separation of designer and builder was manifest in the traditional project delivery process where owners had one contract with the designer and another contract for construction with the low-bid contractor. The builder never saw the plans and specs until he initiated the low-bid process. The process was adversarial with finger-pointing by both the designer and the builder with the owner in the middle forced to arbitrate. Unfortunately universities promoted this separation of disciplines; designer students were taught that contractors were incompetent, less-than-professional companies, bent on cutting corners and making a profit any way possible; construction students were taught that designers are incompetent CAD jockeys with no understanding of the construction process or contemporary materials and methods. It's time to break down the "discipline silos" and begin the integrated delivery process at our universities. The process described in this scenario forces students in the design and build disciplines to work together toward a common goal—winning the design-build competition for a new contract. Student teams begin with built-in prejudices and finish with a new respect for the other's capabilities and an awakening as to the intricacies of the integrated project delivery process.

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APPENDIX

REQUEST FOR PROPOSAL--DESIGN-BUILD SERVICES

XXXX, Inc. is a high-end developer who has been contracted to represent the owner in the design and construction of a new religious facility as described herein. References in this RFP to the "Owner" refer to XXXX, Inc. as sole owner's representatives with authority to make all necessary decisions to complete the project.

PROJECT DESCRIPTION:

The proposed project is a new religious facility to serve an existing religious group that has been organized and functioning for 10 years. The current religious facility, which is badly undersized, is an old elementary school which will be vacated and sold when the new facility is completed; any sales proceeds will be used to offset the costs of the new facility.

SCOPE OF WORK:

- The religious facility is a new [church for a Catholic Church, synagogue for a Jewish congregation, mosque for a Muslim community, etc…..to be selected by the team]
- The group currently has 2000 members and is expected to grow at about 5% per year.
- Attendance at group religious events ranges from 500-1000 with an average of about 650.
- Facilities are required for worship services, religious education and social events.

OWNER'S REPRESENTATIVE:

The owner's representatives are—Instructor 1 Instructor 2

All required contact with the owner during the proposal preparation process should be directed to the owner's representatives in writing.

CONTRACT SELECTION CRITERIA:

XXXX will award this contract to the firm that provides the "best value" proposal that is the most advantageous to the owner. This selection process may result in an award to a firm that does not have the lowest cost proposal.

S/W intends to award this design-build contract based on the following criteria:

1. Firm's qualifications and experience in similar religious facilities.
2. Proven ability to provide design-build services.
3. The qualifications of proposed key team members who will deliver the project.
4. The quality of the design proposed.
5. The financial health of the firm.
6. The firm's preliminary cost proposal.

S/W reserves the right to either bid or negotiate the construction portion of the contract with other contractors. The contractor providing Design Services will have the opportunity to propose a GMP or a Lump Sum for the general construction, but it should not be assumed that this same contractor will have substantial advantages over other general contractors in this regard. Your proposed compensation for Design and Preconstruction Services should reflect the actual costs you will incur rather than assuming these costs can be offset with future construction fees.

SCHEDULE:

- RFP Issued: February 13, 2008
- Mid-point Review March 26, 2008
- Written Proposal Due: April 23, 2008
- Oral Presentations: April 30, 2008[tentative date]
- Design-Build Contract Award July 1, 2008

SITE LOCATION:

The location of the new facility cannot be revealed at this time to avoid local real estate speculation; however, the new location is approximately five acres and is essentially square with a four-lane state road adjacent to the north boundary and a two-lane county road adjacent to the east boundary. The site is essentially flat with an elevation difference of four feet from the north boundary to the south boundary. The surrounding properties are essentially undeveloped and should not influence design. Zoning is not an issue. All utilities are available from the right-of-way on the state road. The new location is in _____ County, Texas. [Your Texas County project location is provided in the "Teaming Agreement" assignment document.]

SITE ACCESS:

Due to the sensitive location of the project site, the competing teams will not have access to the site until the purchase of the site is completed. Site access may not be available until late May, 2008.

INSTRUCTIONS FOR PREPARATION OF YOUR PROPOSAL:

Proposals should include—

1.1 Five copies of a bound narrative volume which is to be printed on letter-sized paper [8-1/2" X 11"]. Limited fold-out materials may be provided if necessary. Lavish color and graphics are NOT desired; however, proposals should be appropriately indexed and tabbed for easy access. Number each page consecutively. Covers, tables of contents and divider tabs will not count as pages. A Table of Contents that includes page number references must be provided. This volume may not exceed 50 pages.

1.2 Two display boards, 24" X 30". One board is to show site layout and floor plans; the other board is to show elevations and renderings. Reduced copies of the boards must be included in the narrative summary volume.

2. The Proposal shall be delivered to the owner's representative shown below:
   XXXX Construction Science Department ,XXXXXX, Texas, Attention: Instructor 1
3. Proposals shall be delivered to Room W009 in the Williams Building within sealed envelopes or boxes and are due no later than 2:00 PM CST, April 23, 2008. Proposals received after the deadline will not be considered.
4. An electronic version of the narrative volume should be emailed to Instructor 1 and Instructor 2 before 2:00PM CST on April 23, 2008.

REQUIRED PROPOSAL CONTENT:

Statement of Interest/Cover Letter

Provide a cover letter that lets us know your level of interest. Provide a brief description of the history and capabilities of your firm and your commitment to this project. The letter may contain any information not shown elsewhere in your proposal.

Related Project Experience

Provide four project profiles of your firm's past experience with similar projects of similar dollar values where you were the Design-Builder and provided design and construction services.

State which projects involved individuals currently employed by your firm, who were in responsible positions directly involved in those projects.

Each project should be described on one page. On this page, include:

- Date design and construction completed
- Final project cost
- Project description, including size
- Project photos
- Project staff & roles
- Relevance to this project
- One client reference for each project, with contact name and telephone

Firm's Financial Stability:

Provide your current Dun & Bradstreet rating, bonding capacity and current standard firm insurance limits for both design and construction.

Project Team:

Provide an organization chart including each team member and the responsibilities of each team member. Provide one-page resumes including all pertinent experience each member has managing similar projects.

Approach and Services:

Describe your approach to project management for both design and construction for this project. Describe any special services you are able to provide. S/W prefers to work with an on-line PM software system and the proposal should reflect contractor's preferences and intentions.

Project Budget:

The not-to-exceed cost for this project is $5.5 million. This budget is for the total project cost and includes all costs to be borne by the owner to provide a complete and useable facility. Any proposal which exceeds this budget amount will not be considered.

Design Requirements:

Teams are required to present **TWO** design options for the facility. For each design option, the team should present:

- A design philosophy narrative statement not to exceed two pages
- A site layout
- Floor plans
- Elevations
- Renderings
- Key materials palette
- LEED certification level proposed
- Energy analysis using ENER-WIN or similar software package

Project Cost:

For each option, provide a detailed conceptual cost estimate for the entire project showing all project costs to include design phase services, general conditions, construction costs using CSI format, FFE, contingencies, bonding and insurance, and permitting. Major cost components must be identified and justified. Conceptual cost estimates must not exceed the project budget. The estimate should include the cost increment to achieve the LEED certification level proposed and the additional cost increment to go to the next higher LEED certification level. The estimate must include stipulated sum amounts for Design and Preconstruction services. Also include a schedule of cash calls so the owner can plan his project financing.

Project Schedule:

The preliminary schedule anticipates award of the design-build contract by July 1, 2008. For each design option, provide a schedule showing major milestones and a substantial completion date. S/W prefers scheduling via SureTrak, but will consider contractor preferences. Your proposal should indicate the date that you will provide a GMP or a lump sum amount for the construction services.

Site Logistics:

Provide and discuss a construction site logistics plan. Include your plans for an SWPPP.

Subcontracting:

Provide a listing of proposed subcontractor packages and discuss you procedures for selecting subcontractors. Include a discussion of the portions of the work to be self-performed.

Value Analysis:

Discuss your process for Value Analysis [Value Engineering]. Provide tradeoff analyses of the materials palette provided in your designs.

Minority Business Enterprises:

S/W expects it contractors to make a "Good Faith" effort to incorporate historically underutilized businesses [HUBs] into the project team. Your proposal should include your plan for involving HUBs to include what portion of the work will be accomplished by HUBs.

Environmental Systems:

Discuss the environmental systems required by your designs. What are the required capacities and how will you provide the required HVAC and electrical systems?

Safety Plan:

Provide your Safety Plan for the project and discuss the most important safety issues on the project and how you will address each. Provide and discuss your EMR for the past five years.

Quality Control:

Discuss your approach to Quality Control/Quality Assurance for this project during different phases of the project. S/W will require mock-ups of major systems; discuss your intentions with regard to mock-ups.

Commissioning:

Discuss your proposed procedures for facility commissioning and warrantees.

Permitting:

The contractor will be responsible for obtaining all required permits. Discuss permits required and the steps you will take to insure the timely receipt of required permits.

Form of Contract:

S/W intends to enter into a Design-Build contract for this work. Your proposal should indicate and justify the form of contract preferred.