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Utilizing Capstone Courses in Separate Fields to Create Real-World Multidisciplinary Team Simulations

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Utilizing Capstone Courses in Separate Fields to Create Real-World Multi-Disciplinary Team Simulations

Abstract

Every day the business world requires stakeholders and companies from multiple disciplines to work together to reach a project's successful completion. Problem solving, teamwork, and communication skills continue to rank as the top competencies required of today's work force. In an effort to better prepare graduates, many academic programs have focused on senior design and capstone courses that create scenarios where students can "fail safely". While capstone courses have progressed to create these simulations, there remains the challenge of creating the real-world complexity of multi-disciplinary teams from different fields. This paper highlights the case study of capstone programs in separate fields and how students were required to collaborate to attain goals specific to their own project's success. No team could attain their final project without the collaborative skills of the other teams. The simulation mimicked the real-world. Within each program students were broken into companies complete with job titles, roles, and responsibilities. Each company was assigned a company in the other program to "contract" for their project. Teams were required to follow scopes of work and determine their timelines and resource allocation. At first, teams focused on the deliverables of one another. As projects evolved, students soon learned that communication, clear expectations, schedules, and accountability were all required more so than their respective discipline skills. With four sessions complete and over 200 students, the program has evolved. The objective of this paper is to share and highlight the history, setup, results, best practices, and candid pitfalls that have resulted from this collaboration for the potential use of other programs.

Key Words: Capstones, Project Based Learning, Interdisciplinary, Simulations

Introduction

In 2010 the School of Construction Management (CM) program at Purdue University was reviewing their curriculum. There was a void at the senior level of coursework where students could highlight their understanding of how their foundation courses were interrelated. Senior design classes in traditional engineering programs highlighted examples. The team recognized that a capstone course would be an ideal platform for students to dovetail their new technical competencies. In conjunction with this development, a team was collaborating with the construction industry to target the competencies required for a successful graduate. Many of these focused on soft skills: communication, problem solving, teamwork, and the ability to convey one's ideas. The team set off to build a course incorporated all of these competencies. The end result is a continually evolving capstone program that focused on creating a real-world simulation. This program allows students a transition opportunity to the expectations of the real-world.

Since the inception, the program has evolved. It started with student teams focused on the same core project. The shortfall of this was repetitive and lacked the ability for teams to "own" their project with their own interpretation. It also became cumbersome for reviewers to assess the same project multiple times. A variety of assigned projects were then introduced allowing customization. The most recent change was to incorporate a capstone program from computer graphics technology (CGT) to partner with the CM student teams. This paper focuses on the foundation of these interdisciplinary teams and the project based learning that has evolved.

Utilizing Literature and Best Practices to Create the Program

Professionals need to be content experts, as well as highly skilled problem solvers, team players, and lifelong learners to meet the challenges head on and remain competitive in the workplace [1], [2]. Necessity to train the next generation of construction industry professionals is recognized as a significant challenge [3]. The capstone project is described as an experience where practitioner and faculty share the project's supervision [4]. Therefore, the conception and execution of the capstone course aims to immerse students in a design-build stimulation.

In the beginning of every semester, students are asked to share their topic of interest (i.e. commercial, healthcare, residential, industrial, infrastructure etc.). The teams are formed based on their listed interest (students with similar interest are grouped together). As further detailed later in the paper, this problem-centered approach, is based on and consistent with the constructivist educational assumption that encourages social and cognitive interactions [5], [6], [7] in the capstone class.

Related literature discusses the concept of an integrated senior capstone course stressing participatory learning and creative problem solving [8]. In the past two years, senior capstone students have collaborated with the students from the Computer Graphics Technology (CGT) department. The CGT teams work with the design-build teams in a capacity of design consultants to deliver the assigned projects. Research indicates that cooperative learning increases productivity, fosters complex problem solving, and strengthens the learning for the individual as well as the group. [9]. The CGT partnership offered in this class is a unique opportunity for students to successfully interact with design consultants to deliver a desired output on time and under budget. The CGT and CM teams collaborate for approximately eight weeks to ultimately produce the design output along with the rendered images for the projects.

The acquisition of skills makes it possible for performance to occur, but without self-efficacy the performance may not even be attempted [10]. The structure of this class not only allows students to develop skills to synthesize both formal and informal construction knowledge to produce an output, but it provides self-realization of how well students can execute courses of action to achieve independent goals as well.

Like the construction industry, most CM and CGT teams work well with each other and among themselves, however, a few teams have had trouble due to communication gaps, mismanaged expectations, unclear instructions and personality differences. As these issues are common in every industry, the instructors consciously share tested means and methods used in the construction industry to address these practical issues. Consequently, faculty members play the role of technical consultants for the student teams [11].

Because the design-build delivery method is used for this course, project size and complexity challenge the time limitations of the semester. As a result, only design and bid phases are scheduled (activities in the pre-construction stage). Bidding requires each team to create a proposal binder that includes both technical specifications and dollar per square feet cost for the project. More importantly, through the BCM capstone course, seniors achieve lifelong competencies which include the following abilities to [12]:

- Adapt to and participate in change.
- Deal with problems and make reasoned decisions in unfamiliar situations.
- Reason critically and creatively.
- Adopt a more universal or holistic approach.
- Practice empathy, and appreciate others' perspectives.
- Collaborate productively in groups or teams.
- Identify personal strengths and weaknesses, and undertake appropriate remediation (self-directed learning and metacognitive skills)

Course Description

Using descriptive information provided by the students, faculty arrange the student group into teams. Teams generally range from four to five students per team and are broken down by each student's specialization or experience level. Teams may be assigned to a Heavy-Civil, Industrial, Healthcare, Commercial, or Residential type project. Teams may also be comprised of students who have declared specializations in either Mechanical/Plumbing or Electrical contracting. Based on the team compositions, unique project descriptions are developed for each team. Instructors intentionally select local sites to allow teams the ability to conduct site investigations, meet with the property owners and become familiarized with the local regulatory requirements. Once instructors' reach a consensus on the identified projects, the locations with the performance requirements for each site are presented to the entire class. After the teams are announced, the teams receive two important documents which provide introductory/design criteria information pertaining to the project as well as the proposal they are to submit. The first document contains specific and unique information pertaining to the location and description of the project. Unless there is a General Contractor and a Specialty Subcontractor assigned to one project, all project teams are preparing a proposal for their own project. This document discloses the specific location of the project as well as high-level descriptive information on the proposed facility they are to prepare a design-build proposal for. This information includes a general description of the building or project along with an approximate size of the project as well as a map and a birds-eye Google type image of the property.

Included in this information are details crucial to the expected form and function of the project. This design criteria may include specifications related to the type and size of the facility or project, the scope of the project, performance requirements, anticipated unit counts, equipment requirements, zoning requirements, or site requirements, as well as information related to quantity of staff, user groups, population to be served, and geographical area to be served. As stated, teams may also act as specific specialty subcontractors such as Mechanical/Plumbing or Electrical subcontractors. Using this information, teams now have the essential information needed to begin considering preliminary design elements which are all taken into consideration when the initial site assessment is performed.

The second document is the Request for Proposal (RFP). The RFP is a very thorough document which clearly states all of the requirements of the written proposal to be submitted as well as the presentation to be conducted.

The RFP is broken down into four distinct sections:

1. Instruction to Proposers for the Construction Management and Design Build Contract - This section includes information related to submittal instructions, issuing office, due date and time, terminology, site investigation, proposal security, clarification and addenda, multiple/alternative proposals, and incurred expenses.

2. Information Available to Proposers - This section is focused on the contract documents.

3. Proposal and Evaluation - This section is focused on the transmittal, the technical proposal, construction costs, construction schedule, project cash flow, proposal criteria, DB/CM team organization, key personnel, resumes, matrix of anticipated staff work hours, matrix of services, phasing plans, quality control plan, logistics plan, and safety plan. This section also describes the discussion and interview process, the price proposal, fees, DB/CM reimbursable costs, general conditions allowances, general conditions non-personnel items, contingency, hourly billing rates, cash flow report, and bid bond. Finally, this section explains the technical evaluation process, the price proposal evaluation process, and the final proposal criteria.

4. Scope of Work - This section discusses the intended project delivery method and discusses requirements for Owner’s contingency and the DB/CM contingency.

Within the first month of the semester, student teams are given weekly assignments which eventually lead to the submission of the DB-CM proposal. Starting with the initial site assessment, students begin contemplating a building/project program which meets and satisfies the design criteria provided to them. Block plans, bubble diagrams, room matrixes, and considerations for height, size and finishes for both exterior and interior are considered and analyzed. While CM students are not educated to be designers, they are expected to utilize knowledge in building materials cost and performance to arrive at a functional yet pleasing project for their potential client.

Once the conceptual design is progressed to an acceptable level, cost estimates, construction schedules, site logistics plans, and general conditions estimates start to be prepared. Once design is more finalized, a detailed staff hour's matrix, a manpower projection report, and a project cash flow forecast are prepared and submitted for review and comment by faculty. Feedback is provided and is expected to be taken into consideration for the final RFP submittal.

The final submittal is tendered per the RFP instructions on a specific date at a specific time. Days leading to bid day and the actual bid day are generally as intense as students will find in a real-world situation. The final hours leading to the bid time, students find themselves finalizing cost estimates, bid bonds, cover letters, resumes, and verifying that all financial data is triple checked, cross coordinated across all documents, and corroborated. The submission is reviewed and critiqued by capstone faculty while student teams prepare for the designated presentation.

Student teams are provided a presentation rubric and told to expect to present to a team of industry representatives including faculty, and invited construction industry partners who volunteer to act as judges for the teams. Industry judges who are usually out of town guests, are provided ample time prior to the presentations to review the teams submitted proposal to gain familiarity with the projects and the proposal. Teams are given thirty minutes to present followed by a ten minute question and answer session. The role of the judges is vital to the success of the presentation process because it is the judges who role play as Owners. As Owners, it is common for them to ask difficult and thought provoking questions of the DB CM presenters. Judges intentionally ask and direct questions to enable the entire team an opportunity to respond to a question. Each team member is then reviewed and scored using a scoring criteria consistent with the rubric provided to the students.

Interdisciplinary Connections

As stated earlier, the CM teams are not educated to be designers, however one of the requirements of the RFP is to provide adequate drawings (elevations, sections, and plans) to convey the proposed DB project to the prospective client. One interdisciplinary connection which is utilized by all groups is the intentional act of being paired with a student from the computer graphics (CGT) department to act as a subcontracted graphic consultant.

The CM teams, through the guidance of the faculty, develop architectural performance requirements for each assigned project. These requirements assist to create the CGT teams' deliverables. Purdue University does not have a traditional architecture program to collaborate with for the design portion. This provides the opportunity for the CM students to expand beyond their traditional skillset. It is worth noting that one of the faculty for this program is a former architect and current plan reviewer for the local jurisdiction. While these tasks are codependent, due to the project uniqueness, the experience of developing architectural performance standards along with creation of the volumetric image for each project was necessary because technology rarely fits into the user environment [13].

This CM/CGT connection allows the teams to experience the act of hiring a subcontractor, setting expectations, agreeing to deadlines, and conducting regular communication to check on progress and quality. The requirement of providing clear direction to the drafter and performing adequate information sharing and collaboration necessary to convey the expectations of the intended design as well as the expectations of the construction management team's design submittal is paramount. This allows the construction management team the opportunity to share both positive and negative feedback to the CGT team in order to fulfill the requirements of the RFP. The CGT team is treated as a hired consultant and is usually shown in the submitted proposal as part of the construction team. At this time, the CGT team is not part of the RFP presentation.

Another interdisciplinary connection becoming increasingly popular is the utilization of specialty subcontractors as part of the DB proposal. Using student teams composed of construction management students with specializations in Mechanical/Plumbing or Electrical, enables two-way communication, coordination, and collaboration throughout the DB preparation phase. This provides real-world experience no different than what students will experience in the working world as general contractors working with specialty subcontractors. This unique relationship requires student teams to collaborate, properly coordinate design, scopes of work, estimates, cash flow, and schedules. In these situations, two proposals may be submitted for one specific project. One proposal from the DB CM and one from the Specially Subcontractor. The two proposals should be in alignment with one another.

One pitfall is the failure of teams in this general contractor / specialty contractor situation to properly collaborate and communicate information in both directions. Milestone deadlines between the teams play a much more significant role to the general contractor / specialty contractor teams because of the dependency on the others information to complete their assigned work item. This mirrors the real world stresses we find in industry daily. Many times this disconnect can transfer to the submissions as it becomes obvious to faculty the two teams are not in sync. Immediate feedback is provided to both team as a way to remedy the situation before it becomes worse.

Communications

The capstone class encourages the teams to utilize the following methods to ensure clear communication. These methods provide framework to achieve both the RFP deliverables and inter-personal expectations for each semester:

1. The team members in the beginning of the semester for each group identify professional roles (i.e project manager, designer, superintendent, CEO etc) to establish team structure.
2. The teams submit an assignment including the details of the deliverables specific to each project as per the RFP to manage the expectations of the other teams.

3. The teams use various design and information sharing tools (i.e. Revit, BIM, Google Drive etc.) available to conduct both independent and collaborative tasks so that the whole process remains transparent.
4. The capstone class provides clear instruction to both CM and CGT regarding collaborative outcomes.
5. As each group dynamic is unique, we emphasize that each member of the team exercise a professional conduct for both direct and indirect communication.

Although these guidelines help develop communication skills, the pieces of the puzzle do not fit together from the beginning and it is through the continuous trial and error process of implementation that eventually lead to a configuration of technology, communication processes and work practices that fit the social and organizational context [14].

Project Based Learning

Project based learning (PBL) has developed into an innovative approach to learning that teaches a multitude of strategies critical for success in the 21st century [15]. What defines problem based learning can be different to each area of education. Our goal was to prepare the students for the real world interacting with people of different backgrounds and areas of specialty- more along the line of outsourcing like a real world construction project. Stepien et. al [16] stated it best, “Problem-based learning is apprenticeship for real-life problem solving. Instead of tidy case studies typical of more traditional problem-solving programs, students find a situation with undefined problems, incomplete information, and unasked questions.” While PBL introduces students to multiple components of learning, assessment of those projects can take on different forms. When incorporating interdisciplinary components, assessment for just project based learning alone was not enough in our determination.

An interdisciplinary component to learning is taking students to a level necessary for today’s workforce. According to Ellis and Fouts [17], interdisciplinary curriculum literature yielded the following claims made by advocates:

- “The interdisciplinary curriculum improves higher-level thinking skills.
- With the interdisciplinary curriculum, learning is less fragmented, and therefore students are provided with a more unified sense of process and content.
- The interdisciplinary curriculum provides real-world applications, hence heightening the opportunity for transfer of learning.
- Improved mastery of content results from interdisciplinary learning.
- Interdisciplinary learning experiences positively shape learners' overall approach to knowledge through a heightened sense of initiative and autonomy and improves their perspective by teaching them to adopt multiple points of view on issues.
- Motivation to learn is improved in interdisciplinary settings.”

"Arguably all student work, interdisciplinary or otherwise, is (or should be) aimed at advancing student understanding"[18].

The incorporation of PBL and interdisciplinary learning came together in our joint-effort semester-long capstone project. It was capstone work for the construction students and was an outsourcing job for the computer graphic students. We knew as educators and as past construction practitioners, that this capstone project would test students' complete educational abilities, but what we had not taken into account was how to assess their collaborative efforts individually or collectively.

Despite all the changes on theory and teaching methods of education, assessment strategies have remained virtually unchanged within this context [19]. The challenge for our interdisciplinary collaboration was to determine how to assess what each group had accomplished and what was lacking. In the real world of construction, companies have the ability to either accept outsourced work as complete or engage in discussions about what was lacking in the work and eventually or ultimately not pay for said work. We as educators took a book from construction and allowed the students to assess the work and collaboration of the outsourced group. A separate rubric filled out by each student from CM and one for CGT about the partnership and collaboration was required a few weeks before the end of the semester. The construction students evaluated the outsourced graphics team on the following eight questions/criteria:

1. The Company we worked with provided us final models on pre-determined deadline.
2. The Company we worked with was responsive to our design requirements and requests.
3. The Company we worked with provided us with design alternatives for the project.
4. The Company we worked with updated us regarding the modelling progress frequently.
5. We could get timely response to any questions or concerns we had.
6. The Company that we worked with us provided an incomplete model.
7. We have worked closely with the Company during this exercise.
8. The Company we worked with has treated us with professionalism.

The CGT students were able to evaluate the construction company group's efforts as well with the following eight questions/criteria:

1. The Company we worked with has provided us with enough documentation so we could provide them with final models.
2. The Company we worked with has not provided us with enough instructions so we could develop final models.
3. The Company we worked with has given a reasonable deadline for the models to be finished.
4. The Company we worked with has explained what their expectations for the finished documents were.
5. We could get timely feedback on any questions or concerns we had.
6. The Company that we worked with gave us conflicting instructions.
7. We have worked closely with the BCM 487 Company during this exercise.

8. The Company we worked with has treated us with professionalism.

The rating for both groups evaluations was on a strongly disagree to strongly agree Likert scale (or 1-5) for each question.

The evaluation of each student in the group was combined to give a complete picture of what the students and groups thought about their counterparts work throughout the semester. The group evaluation of the construction class were given to the graphics instructor to incorporate into their grade for the collaborative project. The group evaluation of the graphics students were given to the construction instructor to incorporate into their capstone project grade. The students were able to include suggestive comments at the end to help improve each group's participation and work as well as future student's experiences.

The challenge at the beginning was incorporating problem based learning with interdisciplinary. After successfully accomplishing integration, assessment of each group's efforts proved to be incomplete from a single instructor's viewpoint. It was decided that letting the students evaluate their counterparts was more effective and accurate than instructors could ever accomplish alone.

In the future of education and preparing our students to enter the workforce, they will not only be judged by their performance, but on their collaboration, negotiation, planning and organizational skills. This capstone and outsourcing project allows each student to experience what the workforce deals with day to day. The class collaboration will have helped them as Bell [15] states, "reflect on how well they worked in a collaborative group and how well they contributed, negotiated, listened, and welcomed other group members' ideas. Students also self-evaluate their own projects, efforts, motivations, interests, and productivity levels." The Students became critical evaluators by giving constructive feedback to each other, which eventually helps them become aware of their own strengths and improve on their interactions with each other as they will need to do in their future construction careers.

Feedback and Assessment

The feedback from those industry partners who act as judges for the RFP presentations are the most vocal about the witnessed demand and result the capstone project places on the students. Reviewing the RFP proposals, its content, and then watching the teams present much of its content is a unique and satisfying experience from the eyes of the industry representative / recruiter. To witness individuals, working as teams, work tirelessly to win a project, enables industry partners to view a side of the student not normally seen during an interview or even an internship. The question and answer session enables the judges panel an opportunity to watch individuals think on their feet and maneuver themselves in and out of difficult situations. In the post mortem session after all presentations are completed, it is not uncommon for the judge's panel to revisit these situations with the entire student audience to enable healthy discussions pertaining to the situation and to provide valuable and immediate feedback.

The project team is in the early stages of assessment. Grading of the course has evolved as it has expanded. There was a concern that there was too much team assessment and not enough individual recognition. This has changed to include a significant number of assignments that are individual. For example each team member is responsible for a submitting a portion of the schedule, prior to the main RFP, that is to later combined into the team schedule after they receive feedback. They receive a grade for their individual portion and for the collaborative team schedule when at the RFP stage. The team has also begun experimenting with CATME teamwork software. This software allows for periodic team assessment and feedback during the project. It also provides a better analysis for providing peer grading. The writing team hopes to expand on this in a future paper.

The capstone process has become popular among the advisory council members and is viewed as a differentiator for our program. The skills learned by the student in a team setting, presenting to strangers, sets the foundation in place for skills which build confidence which foster leadership. The requirements of the capstone project pushes the typical student outside of their comfort zone and enables faculty and industry partners an opportunity to view these results. Common comments include impressive, thorough, hard-working, professional, and effective. The confidence level of the students is enhanced as a result of the experience. At the end, while we are proud of them as faculty, they are proud of themselves for the accomplishment.

Conclusions

The creation of this capstone has spurred a great deal of further study and research including:

1. The analysis of Project Based Learning (PBL) as it relates to construction related curricula.
2. The analysis of interdisciplinary teams and peer assessments.
3. How to recognize and assess the benefit of industry classroom partners.
4. Analysis of how teamwork training may benefit the outcomes of senior projects.

Over the next year, the program team will continue its work and collect data for future expanded reporting on assessment methods for multi-disciplinary teams, best-practices derived from our PBL experiences, additional collaborations in the capstone experience with industry, and expanded teamwork and communication training / simulations planned for the capstone. The recent addition of a major in Design and Construction Integration in the Purdue University School of Construction Management will also provide an opportunity for multi-disciplinary expansion of the design-build capstone simulation. As DCI students from the CM program receive design exposure by attending interior design or architecture studios and become integrated in the capstone course in future years, a new trans-disciplinary environment will become available for study.

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