Design and Implementation of a Specialty Contracting Construction Management Course

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This paper focuses on the design and implementation of a specialty contracting construction management pilot course taught at California Polytechnic State University, San Luis Obispo. The idea for this course stems from the concept to develop an integrated curriculum where construction management fundamentals as well as technical and management contents are taught in a single course that focuses on an individual industry specialty sector of the construction market (i.e. mechanical, electrical, plumbing, etc.). This course was designed to focus on the work of specialty contractors who fabricate and install building systems such as mechanical, electrical, and plumbing (MEP). While the goals and learning objectives primary focused on integrating the technical course content from mechanical and electrical construction classes, the course content area was broadened to include the work from other specialty systems such as fire protection and controls. In addition, learning objectives were included from traditional estimating, scheduling, and other management courses to expose students to the tasks specialty contractors must perform in order to procure and manage projects, as well as their firms.

Key words: Mechanical, Electrical, Plumbing, Integrated Curriculum, Specialty Contracting

Introduction

In recent years, there has been increasing consideration given to the construction areas that fall into the work done by the specialty contractor. This consideration has not translated into more classes emphasizing the specialty contractors' business, only the specific work done by the firm. It is not only our task to teach the nuts and bolts, but as more and more of our student start their careers with specialty contractors, an understanding of their business model also is needed in our curriculum. This is the underlining premise for the development of a specialty lab. Therefore, the technical content was derived from the mechanical and electrical courses, with the understanding that these trades, when combined, represent the greatest portion of work subcontracted by general contractors.

The concept for this course fits into a larger attempt to teach construction management as a series of labs integrating the various courses into an active, applied learning experience that focuses on a particular sector of the construction industry, proposed by Hauck and Jackson (2005). Their proposal seeks to create an integrated curriculum for the Construction Management Department at California Polytechnic State University, San Luis Obispo where the current curriculum is reorganized into seven project-based construction management courses. They are as follows:

- Fundamentals of Construction Management,
- Residential Construction Management,
- Commercial Construction Management,
- Heavy Civil Construction Management,

- Specialty Contracting Construction Management,
- Jobsite Construction Management, and
- Integrated Project Services.

Need and Purpose for a Course on Specialty Contracting

The concept for the project-based course on specialty contracting construction management stemmed from the idea that students become well versed in the residential, commercial, and heavy civil industry construction markets but fail to gain an understanding of the work of the specialty contractors (Johnston, 1990), (Lew and Achor, 1994).

Specialty contractors have always had the need for new graduates but have not always had the success in recruiting students from traditional construction management programs that do not have concentrations in specialty areas or classes that discuss the different business requirements. A number of reasons exist that help explain this problem. First, surveys show that most of the instruction conducted in traditional construction management programs is performed by faculty with only general contractor experience and therefore students do not hear of the issues, problems, and risks associated with specialty contractors (Mouton and Johnston, 1989), (Alter and Koontz, 1996). Second, the work of specialty contractors differs significantly from the work of general contractors in that most specialty contractors who install building systems such as mechanical, electrical, and plumbing (MEP) also fabricate the systems they install (Korman and Tatum, 2006). Third, most specialty contractors also have a service business working for individuals and other businesses, i.e. tenant improvements, renovations, equipment upgrades, etc., thus operate under a different business model than general contractors. Lastly, in order for specialty contractors to be successful they must be able to coordinate their work with the work of other specialty contractors to locate equipment and route connecting elements for each system in order to avoid physical interferences, allow for full system functionality, and comply with differing types of criteria. This process, known to most as MEP coordination, requires representatives from each specialty construction trade to work together to detect, and eliminate, spatial and functional interferences between MEP systems (Tatum and Korman, 2000). Therefore the concept for the specialty contracting construction management course was not only to teach students about each individual system, but also to emphasize the importance of coordination. That way, regardless of whether students are eventually employed by a specialty contractor or a general contractor, graduates would be more familiar with the methods used by the specialty trades in the construction industry and the unique personnel and equipment utilization issues faced by specialty contractors.

Course Design and Learning Objectives

The proposal structured by Hauck and Jackson (2005) allowed for a project-based course in which seven (7) credits/units of laboratory work and one (1) credit/unit of activity work was offered to students who were enrolled in the course. In a ten (10) week quarter system this resulted in a total of nineteen (19) contact hours per week, where students meet four (4) days a week for four (4) hours each day, with three (3) hours a week left as “to be arranged”. Due to the fact that the course was only a pilot course, taught in spring 2006 and proposed for spring 2008, and the curriculum change for the department is still only a proposal during the publication of this paper, the course was designed to fit into both an integrated curriculum model as well as the traditional curriculum model.

In addition, the integrated curriculum model proposal by Hauck and Jackson (2005) advocated that the industry focused courses be taught in a dedicated lab filled with models, samples, contracts, marketing documents, specifications, estimating guides, computer references, and other tools appropriate to that market sector, and which would be available to students in that course all day, similar to a studio in an architecture curriculum. Therefore, the laboratory space was set up as a typical office allowing students to form team groups, fostering collaboration. Twenty-four (24) students formed six (6) teams of four (4) in the laboratory space that was dedicated solely to this course during the quarter term.

With the integrated curriculum model in mind during the specialty contracting course design, the authors sought to develop learning objectives that encompassed construction management fundamentals as well as technical content and the business of being a specialty firm. The technical learning objectives were primary derived from the mechanical and electrical construction courses, which primarily focused on the work of specialty contractors who fabricate and install building systems, such as mechanical, electrical, and plumbing; however, in an effort to broaden the content area to include the work from other specialty contractors, fire protection, and controls were also included. The technical content covered in the course included the following subject areas:

- Heating, ventilation, and air conditioning,
- Water supply and distribution,
- Sanitary drainage and venting,
- Stormwater drainage,
- Gas supply and distribution,
- Fire protection,
- Fire detection,
- Power distribution,
- Grounding,
- Lighting,
- Communication systems, and
- Control systems.

The business content included:

- Risk management,
- Labor productivity and labor control,
- Scheduling labor,
- Estimating on a daily basis, and
- Accounting for the small firm,

Integrating the course content of MEP systems for construction management students is one approach to help change students' and future constructors' thinking to look at the work of specialty contractors as a whole, rather than as independent systems. Therefore, the technical learning objectives were designed to give students detailed knowledge of the active building systems which form a key part of buildings and plants; the approach taken was to analyze the need, scope, design, and construction of these systems as well as address the design-construction integration issues for each system. According to Bonds, Cox, and Gantt-Bonds (1993), arranging content around overlapping concepts and themes helps to enhance and reinforce learning. Integrating the content of the subject areas listed above allowed for the further exploration of connection points between the systems, such as fire-smoke dampers, pumps and motors, flow meters and sensors, fire protection and detection systems, etc. The course was developed and presented with the following goals:

- Define and illustrate the differences between Specialty and General Contractors,
- Describe techniques in estimating and scheduling that are specific to Specialty Contractors,
- Define the need and purpose for active building systems,
- Describe how building systems work, how they are designed, how they fit with architectural and structural systems, and what they include,
- Describe how building systems are built, how long they take to install, and how much they cost,
- Recognize shared knowledge of building systems for design-construction integration,
- Analyze a system design, estimate materials and components used, and create installation work packages for building systems, and
- Compare and select alternate building systems to achieve desired building performance levels

Course Implementation and Delivery

It is the opinion of the authors that the integrated curriculum model described by Hauck and Jackson (2005) provides tremendous opportunities to engage teaching strategies far beyond the common lecture approach typically utilized in many single-subject courses and according to Bonwell and Eison (1991), students learn far more by doing something active than by simply watching and listening. Therefore, with this in mind, the utilization of various methodologies such as cooperative learning and interactive learning stations were attempted. As mentioned above, student formed groups of four (4) in which they would work together throughout the course to accomplished each of the course assignments. The contact hours were divided into several key methods of delivering course content: lectures, plan and specification reading exercises, construction material take-offs, estimating and cost proposal preparation, layout and sizing exercises, construction site visits, installation exercises utilizing interactive learning stations, a specialty contracting firm project, and a system analysis project. Each of these delivery methods utilized is described below.

Lectures and Reading

To introduce a subject matter, an introductory lecture was delivered. Subject areas included: water supply and distribution, sanitary drainage and venting, natural gas supply and distribution, fundamentals of fire protection, building stormwater drainage, fundamentals of heating, ventilation, and air conditioning, power generation, transmission, and distribution; series and parallel circuits; single and three phase power; resistive, inductive, and capacitive elements; and grounding, communication, lighting, and fire detection systems. The lecture format was primary used to enhance assigned readings and convey the most technical aspects of specialty systems, such as pipe friction losses, air duct design, and wire and conduit calculations. Learning objectives related to lecture and readings included:

- Identify and select appropriate piping materials based on the system performance,
- Identify and describe the construction methods and materials used to fabricate and install specialty systems,
- Recognize the function of specialty systems and relevance to the constructed facility, and
- Understand the fundamental features of specialty systems and unifying commonality of the systems, including purpose, function, and physical layout.

Plan and Specification Reading

At the onset of the course student groups were provided with a set of plans and specifications for a building currently under construction at the time of the course offering, the Engineering IV building on the Cal Poly, San Luis Obispo campus. Thus, following the introduction of the subject matter delivered through a lecture, students were required to complete a plan reading assignment. The plan and specification reading assignments required the students to work in their teams to review the set of drawings and specifications for the specialty system that was highlighted. Plan reading assignments for specialty systems directed students to follow each system throughout the building, looking at points of connection and equipment/appliances served by the system. To emulate professional practice, when a specialty contractor reviews a set of plans for the first time, common questions are sought, such as what material is specified, what equipment is specified, etc. Therefore, students were required to answer specific questions regarding the specialty system they were studying. Learning objectives related to the plan and specification reading assignments included:

- Recognize common symbols used to represent specialty system items,
- Recognize and use the appropriate terminology and units of measure used for specialty systems,
- Identify industry standard designations, sizes, and graduations for specialty systems,
- Interpret abbreviations used to reference systems components,
- Describe the flow path of a system and follow the system from point of beginning to all points of use in the facility,
- Identify equipment and materials specified on the plans and in specifications,
- Associate details with plan views,
- Identify main and branch lines of specialty systems, and
- Translate plan view to sections with elevations.

Material Take-off, Estimating, and Cost Proposal Preparation

Following the plan reading exercises, each student team was required to perform a material take-off exercise and develop a cost proposal for each system. To develop cost proposals students were asked to consider labor utilization and productivity, and subcontractor agreements. Learning objectives related to the material take-off, estimating, and proposal preparation included:

- Perform a quantity takeoff for a specialty system,

- Perform a cost estimate and prepare a cost proposal using a price database,
- Differentiate between work performed by the electrical contractor, mechanical contractor, and another contractor,
- Relate the drawings to the specifications, requiring a CSI division number (obtained from the specs) for each take-off item, and
- Recognize the boundaries between electrical and mechanical work.

Layout and Sizing Exercises

For each topic that was presented, an in-class laboratory exercise focusing on the layout and sizing of the system was given to the students. Considering that the design-build project delivery method is becoming more prevalent the exercises were designed to give students practical experience utilizing engineering fundamentals and the use of building codes to layout and size portions of the systems. Learning objectives related to the layout and sizing exercises included:

- Utilize building codes to size elements of specialty systems,
- Quantify the heating and cooling loads for the purpose of sizing and heating cooling equipment,
- Prepare a diagrammatic drawing for conveying system knowledge,
- Determine the total maximum number of water service fixture units (WSFU's) for a facility,
- Determine the water meter size based on the available pressure and total number of WSFU's,
- Determine the total maximum number of drainage service fixture units (DFU's) for a facility,
- Determine the size of branch and main drainage lines based on the DFU's,
- Layout and size ductwork, and
- Layout and size conduit and conductor.

Construction Site Visits

Several construction projects were visited during the course, including residential, commercial, and institutional sites, varying between 30% and 90% construction completion; however the greatest benefit to the students was the ability of the students to visit the Engineering IV project on campus that they were using for the in class plan and specification reading exercises, as well as the material take-off, estimating, and cost proposal exercises. As part of the site tour, students were required to submit a field trip report focusing on the mechanical, electrical, and plumbing systems at each site. Learning objectives related to the construction site visits included:

- Observe construction means and methods utilized to fabricate and install specialty systems,
- Recognize equipment and tools used for fabrication and installation,
- Differentiate between installation practices utilizing prefabrication and on-site fabrication, and,
- Generalize about labor productivity and site conditions,

Installation Exercises utilizing Interactive Learning Stations

Throughout the course, a common interactive learning station was developed for student use.

Students used the interactive learning stations to layout and install portions of mechanical and electrical systems. This included the installation of water distribution and sanitary drainage and venting piping, and wiring of lighting, power, and low-voltage circuits. Each student team was assigned an interactive learning station to use for these exercises.

The rational given to this delivery approach was based on the fact that over the past several years, the building codes that govern the design and installation of mechanical and electrical systems have become increasingly prescriptive in nature, specifying detailed information related to the design and installation of the systems, while offering no reasoning behind their prescriptive measures. It is difficult to be in responsible charge of the construction of an entire building without having an understanding of how and why mechanical systems work the way they do (Wentz and Alter, 1998), (Andersen and Andersen, 1993). For example, in the case of drain waste and vent (DWV) piping systems, the DWV system functions under atmospheric pressure to drain waste from buildings. In order to function properly, a delicate balance between air pressure, hydrostatic pressure, and fluid flow must exist. Students now read about DWV systems in textbooks, and using the building codes, have in-class exercises in drafting the systems, but gain no practical "hands-on" experience with the systems.

The interactive learning stations were constructed of 2" x 4" Douglas fir installed 16" on center, approximately 48" high by 48" wide. The stations were intended to mimic ½ height residential construction, and residential-grade electrical and mechanical components were used throughout. The installation sequence was based upon the progression of lecture material. Mechanically, students were first exposed to water supply and distribution principals. For their learning stations, the students performed rough layouts for typical plumbing fixtures found in residential construction. Next students were introduced to the drain, waste, and venting principals. Using the rough layout the plumbing fixtures, the students were then instructed to install a typical drain, waste, and vent system for the proposed plumbing fixtures. Electrically, students were first exposed to series circuits with resistive loads. For their learning stations, the students used a light switch and two (2) 100-Watt incandescent lamp holders in series. A footcandle meter was used to measure the lumen output one foot from each lamp. The students observed a low level of illumination characteristic of the reduced (60V) voltage across each lamp. The students were then instructed to install a jumper across the first lamp and again measure the illumination. They observed that the light level increased several times due to the full (120V) voltage across the lamp.

The students then installed two duplex convenience outlets and one ground fault circuit interrupter (GFCI) outlet, all in parallel. They were instructed to have a duplex convenience outlet as the first outlet, the GFCI as the second outlet, and another duplex as the third outlet. Also, the third outlet was to be wired to the load position of the GFCI, so that the GFCI provided ground fault protection for both itself and this outlet. They observed that the both the GFCI and third outlet tripped when the GFCI reset button was depressed, but that the first outlet was unaffected. This reinforced lecture material that one GFCI could provide protection for all outlets wired downstream from the GFCI.

The final electrical circuit involved an exercise illustrating a low-voltage inductive circuit, and consisted of a push button, 120V-16V transformer, and chime. Additional electrical devices that could be incorporated into a future workstation include an arc fault receptacle, which is required by the National Electrical Code for bedrooms. An ionizing smoke detector along with a can of smoke could also be incorporated to show how the detector reacts to smoke from a fire.

The laboratory exercises for the interactive learning stations were designed to enhance student learning with the following learning objectives:

- Name and identify the components used in the installation of the specialty systems,
- Describe and perform the installation commonly used on specialty systems,
- Explain the theory behind the prescriptive building codes,
- Develop construction sequencing and installation schedules for the specialty systems, and
- Perform inspections and create reports for specialty systems.

Specialty Contracting Firm Project

To emphasis and further understand the business model that specialty firms operate under, students were required to create a company organizational structure, business model, and marketing plan for their group team. The deliverables for this assignment included a brochure and web site displaying their marketing and business plan. Each team presented their information to the class in the form of a proposal presentation.

System Analysis Project

The culminating assignment for the course was a system analysis project. The primary goals of this project were to synthesize the knowledge they had learned through the course. The student teams were required to independently visit a recently constructed facility, and give a formal presentation on a specialty system installed in the facility. Student work involved interviews with representatives of the owner or the general contractor, the design consultant or engineer in a design-build firm, and the specialty contractor to obtain the information necessary to analyze the design, materials of construction, and installation of the system. The students also were required to review selected design documents to increase their understanding of design and construction requirements and visit the site to review and photograph major elements of the system and installation activities. The key topics in the analysis and group presentation concerned the system and project overview (objectives, size, approximate cost and duration, current status), design of the system (purpose, performance requirements, codes and standards, system type), physical description (major equipment, major subsections, materials of construction), and installation and testing (sequence of installation, construction operations required, requirements for testing). Students were required to design a portion of the system using either varied design criteria or an alternative system type and complete a technical and a managerial analysis of selected topics concerning design or construction of the system. Learning objectives related to the system analysis project included:

- Develop criteria for use as the basis of design,
- Provide cost alternatives and value engineering options for specialty systems,
- Perform system redesign to consider energy savings,
- Demonstrate justification for design intent, and,
- Identify critical components in specialty systems.

Discussion and Recommendations for Future Implementations

Compared to students being taught via the traditional lecture mode, the cooperative environment provided a forum in which a deeper understanding of the material could occur and motivation could be placed on learning and achieving a common goal (Felder and Brent, 1994). However, since the majority of the student's work was performed in a group setting, individual assessments became a challenge and were handled through individual quizzes and exams. Student feedback from the course was found to be positive to the aspect that the course was able to fully introduce them to the scope and impact of mechanical and electrical systems and the types of organizations and firms. However, from a teaching perspective, the course preparation time seemed to be significantly greater then that of a stand alone mechanical or electrical course due the fact they the course attempted to cover much more then the technical aspects regarding specialty systems.

It is the authors' opinion, that in order for students to excel in a course environment such as this, it is critical that they have a strong foundation in construction fundamentals. Thoughts on improvement may include having a separate lecture based course on the specialty systems individually, rather than trying to teach an entire system from little or no foundation to teaching about managing a specialty-contracting firm. In addition, to better prepare students, a future offering of the course may include exercises in MEP Coordination, exposure to Building Information Modeling (BIM), and additional estimating and scheduling exercises, where students create work packages for fabrication and installation of specialty systems.

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