AC 2008-502: DESIGN AND USE OF INTERACTIVE LEARNING STATIONS IN CONSTRUCTION EDUCATION FOR BUILDING MECHANICAL, ELECTRICAL, AND PLUMBING SYSTEMS

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Design and Use of Interactive Learning Stations in Construction Education for Building Mechanical, Electrical, and Plumbing Systems

Abstract

Over the past several years, the building codes that govern the design and installation of mechanical and electrical systems for buildings 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. Students now read about the design and installation of these systems in textbooks, and using the building codes, have in-class exercises drafting the systems, which in industry are used for fabrication and installation. Therefore, in conjunction with a new curriculum proposed for the construction management department at California Polytechnic State University (Cal Poly), San Luis Obispo an interactive learning station was developed for student use to enhance student learning. This paper focuses on the design and use of interactive learning stations for building mechanical, electrical, and plumbing (MEP) systems that allow construction students to perform "hands-on" fit-up exercises and test their performance.

Introduction and Background

In recent years, there has been increasing consideration given to integrated curricula by construction engineering and management faculty and industry advisors. According to Hauck and Jackson[3] each proposal has tried to address core problems associated with an overly segmented curriculum and the lack of project based learning in different ways. A model proposed by Hauck and Jackson[3] attempts to teach construction management as a series of labs integrating the various construction management courses into an active, applied learning experience. Their integrated curriculum proposal for the construction management department is centered on the creation of seven project-based seminars. They are as follows:

- Fundamentals of Construction Management
- Residential Construction Management
- Commercial Building Construction Management
- Heavy Civil Construction Management
- Specialty Contracting Construction Management
- Jobsite Construction Management
- Integrated Services Construction Management

Each of the project-based seminars is based on a model of seven quarter-hours of lab and activity credit for a total of nineteen (19) contact hours per week. Similar to a studio in an architecture curriculum, each seminar was proposed to 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 available to students in that seminar all day.

The concept for the specialty contracting construction management seminar was to emphasize the work of specialty contractors who install mechanical, electrical, and plumbing (MEP) systems. Their work is typically very specialized and their work is effected by, and affects the work of, all other specialty contractors who install MEP systems. Furthermore, MEP systems involve intense coordination during the design phase of building construction that requires the work of several trades to locate equipment and route connecting elements for each system to avoid physical interferences, allow for full system functionality, and comply with differing types of criteria[4].

In the spring of 2006 (and proposed for Fall 2008), a pilot lab course integrating two independent courses that focus on (MEP) systems was developed and offered at Cal Poly for construction management and engineering students. The course curriculum focused on integrating the course content of MEP systems with regard to design, construction, and coordination issues commonly found among specialty contractors. Therefore, whether students are eventually employed by a specialty contractor or a general contractor, they will 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.

The integrated curriculum model described by Hauck and Jackson[3] provides tremendous opportunities to engage teaching strategies far beyond the common lecture approach typically utilized in many single subject courses. Various methodologies such as cooperative learning and the use of interactive learning stations can easily be utilized in an integrated learning lab environment. The integrated approach to construction management education requires students to be active participants in their own education, students learn far more by doing something active than by simply watching and listening[2]. Therefore, to take advantage of the studio-laboratory format of the course proposed in the new curriculum, a common interactive learning station, which integrated the MEP systems, was developed in order to enhance student learning.

Course Approach, Learning Objectives, and Delivery Method

The integrated course described above was designed to introduce students to the scope and impact of MEP systems for buildings. The mechanical and plumbing systems included in the course content included: heating, ventilation, air conditioning, plumbing, and fire protection, while the electrical systems include power, grounding, lighting, communication, and fire detection. Primarily 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. The course was developed and presented with the following learning objectives:

- Define the need and purpose for active MEP 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 it takes, how much it costs
- 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
- Compare and select alternate building systems to achieve desired building performance levels

The class was divided into several key methods of delivering course content: lectures, lab exercises, construction site visits, plan reading and material take-offs, and the use of interactive learning stations. Introductory lectures were given on each subject matter. For mechanical and plumbing topics included water supply and distribution, sanitary drainage and venting, natural gas supply and distribution, fundamentals of fire protection, stormwater drainage, and fundamentals of heating, ventilation, and air conditioning. Electrical topics included 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. Lectures were primarily used to enhance assigned reading and convey the most technical aspects of MEP systems, such as pipe friction losses, air duct design, and wire and conduit calculations.

Following the introductory lecture and a reading assigned, an in-class lab exercise was given for students to work on. Lab assignments varied by subject matter but primarily included system sizing and layout, construction document reading, preparation of cost proposals, and estimating and scheduling exercises. The plan reading and material take-off exercises required the students to work within their three-person teams and review a set of mechanical and electrical drawings and specifications for an instructor-selected building located on campus. In addition, several construction projects were visited during the course, including residential, commercial, and institutional sites, varying between 30% and 90% construction completion. Following each site tour, students were required to submit a field trip report focusing on the MEP systems at the site. Finally, throughout the class, a common interactive learning station with related laboratory exercises was developed for use in the course, which allowed students to perform “hands-on” fit-up exercises of MEP systems and test their performance. The following paragraphs illustrate the design of these interactive learning stations and their use, including the learning objectives and outcomes assessments.

Interactive Learning Stations

As stated above, over the past several years, the building codes that govern the design and installation of MEP systems for buildings have become increasingly prescriptive in nature, specifying detailed information relating to the design and installation of the systems, while offering no reasoning behind their prescriptive measures. 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. If designed and installed improperly, noxious gases may be produced and may enter the building and waste will not properly leave the building. System performance depends highly upon quality installation, which is the primary reason why building codes have opted to write codes in a prescriptive manner.

Students now read about DWV systems in textbooks, and use the prescriptive building codes to draft diagrams the systems - which in industry are used to fabricate and install the DWV systems, but fail to understand the physics behind why DWV works and often cannot adapt the code to situations which are not specifically prescribed in the code. Several practices are used for the installation of DWV piping in buildings. These include, but are not limited to the following:

- Individual Fixture Draining
- Combined/Common Venting

- Branch Venting
- Wet Venting
- Group (Circuit and Loop) Venting

Another common example of this is the building electrical system. Students learn about installation of electrical systems in building in textbooks, and using the building codes have in-class exercises producing one-line wiring diagrams, but fail to understand how the systems work properly and gain no hands-on experience with wiring and therefore fail to gain an appreciation for the field trades who install the systems. Several practices are used for the installation of electrical systems in buildings. These include, but are not limited to the following:

- Normal and emergency power
- Supply voltage
- Distribution equipment
- System grounding

Therefore, the authors' idea was to utilize a common interactive learning station for MEP systems to enable students to gain practical "hand's-on" experience to enhance student learning.

Planned Learning Objectives

The interactive learning station originally proposed was envisioned to be a laboratory tool that would enhance students' understanding of MEP systems beyond the textbook explanations by allowing students to observe how MEP systems perform in addition to allowing them to gain "hands-on" experience of performing DWV piping fit-ups. By using the interactive learning station, students would be able to test each of the many practices commonly used for the installation of MEP systems. Laboratory exercises for the interactive learning stations were designed to enhance student learning with the following learning outcomes and objectives:

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

Design of the Interactive Learning Stations

It was conceived that students would be given architectural layouts of proposed MEP fixture locations with a wall section of a building. Students would be required to produce diagrammatic installation drawings and then have the opportunity to fabricate, test, and analyze the performance of their system.

In a typical construction management program course, classes usually range from 20 to 24 students and it was envisioned that students would work best in groups of two (2) or three (3). Therefore, eight (8) to ten (10) stations would need to be fabricated for students use. Preliminary dimensions for the DWV interactive learning station were estimated to be 48" high by 36" wide. The interactive learning station was proposed to be constructed from 2" x 4" wood stud framing members; similar to what students will find in the wall framing section commonly used in residential construction.

So that framing sections could be reused each course offering, it was envisioned that they would be fabricated so that they would not have to be modified and that they could accommodate multiple types of MEP systems and installations. Following that reasoning, once a student group fabricated and tested an installation, they would need to be able to disassemble their fabrication so that another installation could be fabricated and installed to demonstrate another type of system.

Use of the Interactive Learning Stations

During the initial pilot course offering the interactive learning systems 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. Photos were taken at various stages to illustrate the growth of the student's learning during the 10-week course. The basic workstation is shown in Photo 1.

Photo 1 – Basic Workstation

Over the course, the interactive learning stations were used by students to design and install portions of mechanical and electrical systems. These included installation of water distribution and sanitary drainage and venting piping, and wiring of lighting, power, and low-voltage circuits. The development of the MEP installation was based upon the progression of lecture material. For the mechanical and plumbing work, 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. For the electrical work, 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 foot-candle 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. These stages are shown in Photo 2 and 3.

Photo 2 and 3 –Workstation with Drainage System Installed and Electrical Rough-in Started

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. A completed workstation is shown in Photo 4.

Photo 4 – Completed Workstation

Outcomes Assessment

As a result of implementing and using the proposed Interactive Learning Station, the students were able to perform the following new and enhanced learning outcomes and objectives:

- Name and identify the components used in the installation
- Describe and perform installations
- Explain the theory behind the prescriptive building codes
- Perform installations of systems according to building codes
- Develop construction sequencing and installation schedules
- Create a "Bill of Materials" for fabrications
- Estimate fabrication and installation schedules
- Advise others on the installation techniques and practices commonly used
- Test installations
- Perform inspections and create inspection reports

Examples of assessments that were used in the laboratory where students have used the Interactive Learning Station included the following:

- During an examination period, students were shown an installation, constructed with the Interactive Learning Station, and asked to write an inspection report and identify installation errors and/or potential problems.
- Students were asked to give an oral presentation in which they were required to give a presentation to the class on a particular system that they built using the Interactive Learning Station.
- For a quiz, students were shown a particular assembly constructed with the Interactive Learning Station, and then were required to use the Interactive Learning Station to produce diagrammatic installation drawings.

Discussion and Recommendations for Future Implementations

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 MEP systems as a whole, rather than as independent systems, which helps to enhance and reinforce learning by arranging content around overlapping concepts and themes[1]. The use of the common interactive learning station for the MEP systems further helped to reinforce connection points between the multiple systems. Future laboratory exercises using interactive learning station may include such MEP system components such as fire-smoke dampers, pumps and motors, flow meters and sensors, fire protection and detection systems, etc.

The student work preformed on the interactive learning station also emulated the MEP coordination process where representatives from each specialty construction trade work together to detect, and eliminate, spatial and functional interferences between MEP systems[5]. In order to install the MEP systems in the interactive learning station, students were forced to consider design, construction, and operations and maintenance criteria in order to achieve proper functioning systems.

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 take place and motivation could be placed on learning and achieving a common goal[6]. Use of the interactive learning station encompasses many of the seven principles of good practice for education by encouraging contact between students and faculty, developing reciprocity and cooperation among students, encouraging active learning, giving prompt feedback, and respecting diverse talents and ways of learning.

The interactive learning station allowed an enhanced level of student-faculty contact by allowing the students and faculty to work together in a fashion other than the traditional lecturer-listener relationship that is most commonly found. Use of the interactive learning station encouraged students to work with their peers and the faculty member to achieve the above listed learning outcomes. The interactive learning station also encourages active learning by experimentation and gave students prompt feedback by allowing students to test their mock installations.

The interactive learning station also allowed students to learn in a multitude of ways by allowing students of all learning styles to develop from laboratory experiences related to the interactive learning station. From our observations kinesthetic learners benefited from the "hands-on" fit-up exercises, visual learners benefited from being able to observe the simulated waste flow in the piping, and auditory learners benefited from working in student groups by either giving or receiving fit-up installation instructions.

It is the author's opinion that the interactive learning station is innovative in the fact that it is a laboratory tool that focuses on getting "back-to-basics". As described above, the building codes that govern the design and installation of MEP systems have become increasingly prescriptive in nature, while offering no reasoning behind their prescriptive measures. Furthermore, the authors felt that computer programs that offer visualization capabilities could assist in the students learning; however, it was the physical hands-on fit-up experience described above that best enhanced student learning.

Upon graduation, most graduates of construction management departments take positions with construction companies and are placed into roles as field engineers and construction managers, or take positions with owners as facilities managers, owners' representatives, and construction inspectors who perform quality control task. Often they are asked on construction jobsite "How can you manage construction if you have never performed construction yourself?" or "What qualifies you to inspect my work?" Use the interactive learning station allows a students to qualify themselves by giving them the hands-on experience in installation and testing MEP systems and furthermore giving them the capability to describe the theory behind the building code and to explain the effects of improper installations rather than just citing the building code.

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