

C4P Construct for Practice – The Integrated Construction Laboratory

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Construction contractors need entry-level personnel who can communicate and collaborate effectively with the different members of a project team. It is important for undergraduate Construction Management programs to address these demands using curricular approaches that challenge the traditional compartmentalized structures found in our academic institutions. This paper describes an integrated laboratory that we call Construct for Practice (C4P) that breaks with the traditional academic practice. The C4P approach uses a vertically integrated approach to instructional design where teams of sophomores, juniors, and seniors are charged with the design, construction and management of a physical building mockup. Preliminary findings indicate that students are developing an appreciation for the importance of communication, planning, and teamwork.

Key Words: integrated laboratory, integrated curriculum, experiential learning, collaboration

Introduction

Multiple studies indicate that communication skills are one of the most important characteristics of an effective Construction Manager (Gunderson & Gloeckner, 2011; Mead & Gehrig, 1995). Over the last decade, several trends have developed that are changing the ways that people communicate with each other on construction projects. The maturation of wireless Internet networking enables teams of designers and construction managers to exchange drawings and information through email and FTP. PDF files have largely replaced paper drawings, and construction managers increasingly use tablet computers and programs like Bluebeam to exchange information and update drawings in the field.

At the same time, owner demands for quality, speed to market, and reduced costs have led to the development of new contractual arrangements between traditional construction teams. Particularly on complex projects, traditional Design Bid Build (DBB) project agreements are being replaced with new agreements like Construction Manager at Risk (CMAR), Construction Manager/General Contractor (CM/GC), Design Build (DB), Public Private Partnerships (PPP) and most recently Integrated Project Delivery (IPD). Many of these delivery methods use building information models to help teams visualize the project design and solve problems associated with construction complexity. These project agreements also emphasize communication and collaboration between contractor and architect and owner. In 2007 the AIA California Council developed a definition for IPD that noted: “At a minimum, though, an integrated project includes tight collaboration between the owner, architect/engineers, and builders ultimately responsible for the construction project from early design through project handover.” (Edmonson & Rashid, 2011). The adoption of LEAN construction techniques also emphasizes the alignment of goals and precise project communication in an effort to reduce waste and improve project performance (Howell, 1999).

Given these trends, construction contractors are demanding entry-level personnel who can communicate and collaborate effectively with all the members of a project team. At a recent meeting sponsored jointly by the American Council for Construction Education and the Associated General Contractors, a multidisciplinary group of academics, construction professionals, designers, and government officials were asked to develop and prioritize a list of competencies that could be applied to construction education programs. During one local session, the top competencies focused on effective communication skills, including “apply communication skills to function effectively in a diverse team.” This process has been replicated in a series of national meetings, and the results are currently being distilled into a draft set of learning objectives by ACCE (ACCE 2012).

An integrated approach to learning may help provide solutions to some of these challenges. In this paper, we describe how we have integrated the instruction of construction materials and methods with the concepts of design build and project management. We call this concept **Construct for Practice or C4P** for short. Additionally, we will outline a long-term longitudinal study that we are using to assess the effectiveness of the integrated approach.

Integrated Curriculum

The integrated curriculum is not a new idea. In 1642, Henry Dunster, the founder of Harvard, introduced the traditional course of study using a model that was institutionalized in Europe in the 13th century. Morning classes were devoted to recitation of the classics, followed by afternoon debates that integrated the philosophies of Aristotle with the trivium, quadrivium, and the study of theology. The introduction of elective study by Andrew White at Cornell in 1866 and the rise of prominence of technical and scientific fields during the Industrial Revolution led to the university structure that we see today; in which students can define their own course of study (Rudolph, 1977). While the college degree and course of study define the path of the student, the inherent flexibility of the system has had the result of making the single college course stand on its own. Froyd and Ohland (2005) question whether compartmentalized courses provide a learning environment in which students can develop knowledge across course and disciplinary boundaries. Studies from the field of cognitive science inform us that for a person to learn, elaborate networks of associations must be formed in the brain. These elaborations involve placing personal interpretation on learned material, in which meaningful stimuli are processed more deeply and more quickly (Craik & Lockhart, 1972). It is important, therefore, that the learning environment be structured such that students are exposed to meaningful situations that motivate them to build and strengthen their understandings. Drawing on Lewin, Dewey and Piaget, Kolb (1984) defines learning as “the process whereby knowledge is created through the transformation of experience” (p. 38). In the field of construction education, the physical laboratory is one device in which Kolb’s experiential learning can take place. Unfortunately, the construction laboratory typically is dedicated to isolated topics and thus suffers from the same sort of compartmentalization that affects other courses in the traditional curriculum model. This compartmentalization creates an expectation that students will make connections among the different aspects of construction management on their own (Hauck & Jackson, 2005). An integrated curriculum can help minimize some of these compartmentalization challenges.

In an integrated curriculum, students from the sophomore, junior and senior levels work together to meet the learning objectives defined in a single class. This approach allows older students to help teach and mentor younger students, which can help build a culture of learning across a broad population of ages, talents and personalities. At the same time, the integrated approach creates a communal approach to learning where teams instead of individuals are asked to analyze problems and develop solutions. This can improve the communication and teaming skills that are essential to today’s multi-disciplinary construction projects. If designed properly, an integrated curriculum can also provide leadership opportunities where older students are charged with organizing and leading projects to successful completion. While the integrated approach is not new, it has not been used widely in construction education until recently. In the mid-1990s, Virginia Tech instituted a vertically integrated theme in their program where students from different classes were asked to work together on collective commercial, residential and heavy civil projects (Mills, Auchey, & Beliveau, 1996). More recently, several institutions have implemented a design studio approach where students are asked to frame a problem, brainstorm ideas, and develop solutions to construction problems at Cal Poly (Hauck & Jackson, 2005) and University of Washington (Rojas & Mukherjee, 2005). Other groups at the University of Oklahoma and Colorado Mesa University are currently experimenting with a hands-on laboratory approach where students work together to build mockups of typical construction assemblies.

Context

The Construction Management program at Northern Arizona University has a long tradition of hands on learning. The program evolved from a vocational education program in “industrial supervision” and many of the classes were structured as lecture classes that focused on residential construction. The classes, which were highly compartmentalized, were dedicated to individual subjects including concrete, masonry, and electrical systems. As the program matured, the faculty began to focus on commercial and heavy/highway construction, and the labs became increasingly outdated.
Additionally, large class sizes and inadequate facilities compromised the effectiveness of the instruction. Student evaluations of these experiences were consistently mediocre, and the program set out to improve the lab experience

as part of its strategic planning process. In 2011, the faculty developed an integrated approach to the labs that combined hands-on learning with more modern concepts in design build, building information modeling, and project management. Much of our work was inspired by the vertically integrated curriculum at Virginia Tech (Mills et al., 1996), as well as the laboratory approach that was recently developed at the University of Oklahoma. Working collaboratively, the faculty conceptualized and refined the program during the 2011 academic year, and the concept was vetted with our industry advisory board in spring of 2012.

C4P Program Description

Our integrated laboratory system combines elements of design, construction and project management to give students a better understanding of the construction process. We call this approach **C4P or Construct for Practice**. The C4P approach uses an integrated approach whereby teams of sophomores, juniors, and seniors are charged with the design, construction and management of a physical building mockup.

The mockups are approximately 8 foot by 8 foot in size and they contain many of the elements of a traditional commercial building, including concrete foundations and formwork, light gauge steel wall and ceiling elements, waterproofing and flashing systems, brick and block work, acoustical ceilings and drywall. Additionally, each mockup includes basic electrical, lighting, plumbing, and ventilation systems. A model of the mockup is shown in Figure 1.

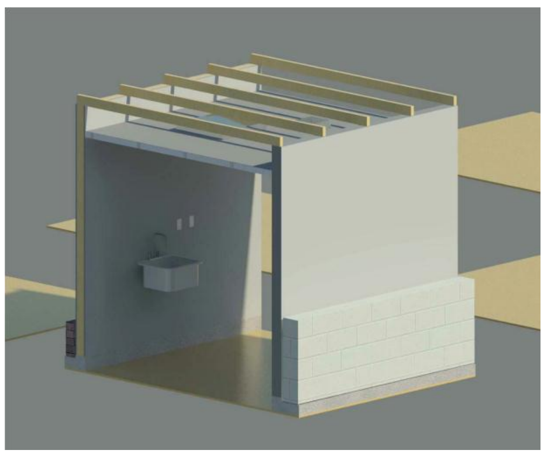

Figure 1: Model of Mock-up

CM200L: The sophomore students act as the **Project Build Team.** Like subcontractors on a project, they are responsible for constructing individual mockups per the plans and specifications. This work includes erecting forms, placing rebar and setting embeds, mixing and pouring concrete, erecting steel partitions, installing sheathing and exterior waterproofing, laying up brickwork, and installing the MEP and finish elements associated with the project. They are also asked to document progress through daily logs and resolve construction issues through the RFI process. In this way, they work closely with the senior management and the junior design teams.

CM300L: Junior students act as the **Project Design Team** where they assume the role of the project architect or design engineer. Their primary job is to develop the construction documentation for Management and to build teams to construct each mockup. They are in charge of developing digital models, specifications, as-built drawings, shop drawings, and coordination drawings. Additionally, they have to respond to RFIs that are generated during the construction process.

CM400L: Senior students act as the **Project Management Team** for the mockups. In this role they are charged with managing project costs, project quality, and the project schedule. These senior teams are also in charge of creating and delivering toolbox safety talks, maintaining as-built drawings, and developing recommendations for improving construction operations. Perhaps most importantly, the seniors are asked to take a leadership role in mentoring and teaching the juniors and sophomores about the best methods to accomplish individual tasks.

Professional Skills, Knowledge and Attitude Objectives

During the creation of C4P, the development team outlined learning objectives for the integrated effort as well as for each of the individual labs. To meet space requirements, we have only included the overall program objectives here. They include:

- Create a Building Information Model that contains design, cost, and schedule elements required for the successful completion of the project.
- Design toolbox talks that can be used to identify and mitigate hazards and train students in the elements of construction safety.
- Create specifications, shop drawings, and coordination drawings that illustrate exactly the design of the project.
- Create procedures that can be used to measure and document construction quality on the project.
- Design a cost and scheduling control system that can be used to monitor progress and predict future costs.
- Construct a complete commercial building mockup that meets the owner's design requirements.
- Manage the project through weekly team meetings, look ahead schedules, meeting minutes, design briefs, requests for information, and as-built drawings and models.
- Write weekly progress reports that document progress, analyze construction deficiencies, and measure schedule and cost compliance.
- Write a final report that summarizes all of the activities associated with the project and provides ideas for the improvement of future projects.

Implementation

The C4P lab was first offered in the fall of 2012. During the preceding summer session, the C4P instructors worked together to develop the learning objectives and outline the individual class activities. As a team, the instructors built an exact copy of the mockup to develop an understanding of construction and safety issues. To streamline the process and eliminate risks associated with power tools, many of the components for the mockup construction are modularized or prefabricated by instructors or lab aids. To minimize cutting and improve safety, the walls and ceiling systems are dimensioned to use a two-foot grid. Forming systems are pre-cut, and the electrical system uses modular armored cable. In this way, most of the components can be reused for future projects, and the students develop an understanding of modular assembly and prefabrication. This also reduces the overall cost of the laboratory.

We have designed C4P to allow for the construction of six individual mockups each semester. Individual teams composed of four seniors, four juniors, and four sophomore students construct each of the mockups. This group of twelve students works collectively to design, construct, and manage the construction of a mockup each semester. A total of six groups of twelve students (72 individuals) can be involved with the C4P project each semester. To help replicate the design and construction process, each individual group acts like a mini design build firm.

The mockups are constructed in a warehouse type facility that is approximately 2500 square feet, located off campus. We rented this facility from the local Carpenter's Union Hall. Individual lab fees cover the rent. This facility, which we call the project site, has a plywood floor built above the concrete slab for the purpose of easy attachment of forms, walls, and other elements. Like a real project, the build teams and management teams work together on site, while the design teams work remotely at our computer laboratory on campus. Information is transferred between the design and build teams via the Internet to computers on site. Currently, we are using EA Doc, a cloud based project management system, to document and archive project information including daily logs, digital pictures, RFI's, quality programs, safety programs and other digital information.

Students use Autodesk Revit, a building information modeling (BIM) program, to develop the design and coordination documents needed for each project. To help understand the design build process, C4P uses a fast-track process where the construction is tightly sequenced with the design process. For instance, while the build teams are working on the foundations, the design team is completing the drawings for the wall and roofing systems. In this way the design is developed a week ahead of the work scheduled. This gives the students a real feel for some of the time pressures associated with the construction process. Instructors for each of the labs use a master schedule (Figure 2) to help sequence the management, design, and management activities during the semester.

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Build Team														
Tasks	Kickoff Meeting	Safety Orientation	Drawing Review Layout	Form, Reinforce Place	Walls & Roof Framing	Sheathing, Waterproof, Flashing	Masonry	Plumbing Rough	Electrical Rough	Interior Drywall ceiling	Above Ceiling light mechanical	Finish MEP, trim	Close Out	
	Team building	safety	use 100% geometry	use 100% structural	100% envelope	100% envelope	100% envelope	100% MEP	100% CD	100% CD	100% CD	100% CD	Complete Punchlist	
Design Team														
Tasks	Kickoff Meeting	Geometry	Structural	Envelope	Finishes	MEP	MEP	Final Drawings	RFIs	RFIs	As Built - Record Drawings	As Built - Record Drawings	As Built - Record Drawings	
Drawings	BIM Templates	100% geom. 60% structural	100% structural 60% envelope	100% envelope 60% finishes	100% finishes	60% MEP	100% MEP	100% CD				Punch List	As Built Drawings	Final Report
Specs		concrete masonry framing	sheathing waterproof flashing	Ceiling drywall paint		Mechanical Electrical Plumbing								
PM Team														
Tasks	Kickoff Meeting		Project Execution Plan	Project Schedule	Project Estimate / Budget	Document Control Plan	Cost Control Plan	Quality Control Planning	Project Control & Evaluation	Project Control & Evaluation	Project Control & Evaluation	Project Control & Evaluation	Project Control & Evaluation	
Deliverables		Project Plan	Project Schedule	Concrete Safety	Ladder Training	Haz Materials	Masonry Safety	Electrical Safety	Back Injury Prevention	Scaffold Safety				

Figure 2: C4P Master Schedule

Students document the progress of the building efforts with digital photographs and digital video. These videos show the steps required for each task. We anticipate a time when the students will be able to watch these videos before coming to lab, eliminating training time on site.

Prerequisites

We have designed the C4P classes to act as critical milestones in our degree progression. Typically, students have to complete the 200 level lab before moving on to their junior level classes. Similarly, the 300 level lab has to be finished before moving into the senior level classes. This allows us to align the teaching in our lab classes with the curriculum that is being taught in other individual classes. To keep class sizes reasonable and improve progress toward graduation, the C4P classes are offered each semester.

Staffing

To help with class management, grading, and control, we run the C4P program as three individual laboratories that carry one semester hour of credit. These classes are labeled CM400L, CM300L, and CM200L, and an individual instructor is assigned to each class. To ensure an integrated experience where students work together, the classes are all scheduled at same time on Friday mornings from 7:00 – 10:00 am, and attendance is mandatory.

Like the students, the three instructors work collectively as a team to manage the overall projects. The CM400L instructor directs the seniors on project management and leadership issues, while the CM300L instructor helps train students to use Revit and manage the flow and accuracy of design information. The CM200L instructor is responsible for the oversight of the mockup construction. He/she procures materials and instructs students in proper construction assembly techniques. As many of the sophomore students have never completed a single construction task, this class requires close coordination and supervision.

As part of the build lab (CM200L), we are also utilizing local construction trade experts to demonstrate how individual products like electrical systems, plumbing systems, brick, and acoustical systems are installed. At the beginning of each class, a professional demonstrates the proper procedure for mixing mortar or terminating electrical connections. Students can ask questions about the installation and receive immediate feedback from a seasoned professional. These experts also help supervise the students and provide advice as they complete their respective tasks.

Assessment

Each student receives an individual and a group evaluation. The assessments, which are closely linked to the learning objectives, include student self-evaluations, peer evaluation, as well as instructor evaluations. Students are also asked to develop a final report that describes what they have learned and how the projects can be improved. Some specific assessment components include attendance, collaboration and communication, quality of deliverables, and schedule compliance.

Preliminary Results

The sophomore student project build teams began the semester with limited knowledge of the objectives associated with the new integrated construction laboratory. When students arrived at the off campus project site, they were able to look at a mockup that had been completed by the faculty. This allowed them to visualize the construction and relate their future work to project plans. Many of the students have limited previous construction experience. Some of the more experienced students have worked on framing crews, but a large group of the students have never picked up a hammer or used a power tool. In the future, we will assess the construction experience of individual students in order to pair experienced students with inexperienced students. We feel that this will improve mentoring, minimize frustration, and allow the teams to work more effectively.

Interestingly, the C4P approach has already created many situations that mimic real world construction projects. Students have been frustrated by the incomplete plans and specifications associated with the fast track process. When the plans are incomplete and key information is missing, the build teams have had to issue RFI’s to resolve the problems. Students quickly realized that if they waited until the day of installation to review the drawings and specifications, they would not have all of the information that they needed, and their projects would be delayed. Consistent with actual construction projects, students are beginning to understand how information is related to meeting deadlines and schedules.

As expected, communication has also been a challenge. In order to communicate effectively, the students have had to learn the on-line project management software and they have experienced the challenges of on-line interaction. Students use EA Doc to receive plans and specifications, write daily reports, and send/receive requests for information (RFI’s), so they are developing a good understanding of the document control process. They are also beginning to understand that unclear written communication often results in misunderstandings and project delays.

These problems have forced project build teams to focus on concise, clear, and timely language in their RFI questions. Initially, the students wrote daily reports that were verbose and difficult for the other teams to understand. As a result, the build teams were forced to re-write their reports to help other team members understand what was happening on the project site.

Another challenge has been project quality. Lack of precise measurements and attention to detail during early lab sessions resulted in construction problems with subsequent assemblies. For instance, anchor bolts interfered with plumbing rough-ins and brick shelves compromised waterproofing assemblies. Students began to realize the importance of minding the details and anticipating the next operation in the construction sequence. The quality inspections made by the project design teams, project management teams, and lab aides acting as third party inspectors revealed work that had to be demolished and reconstructed before final sign-offs. Understandably, the students were frustrated by the experience, but they are also now paying more attention to the plans and specifications and the accuracy of the assemblies.

On the design side, the C4P program has already yielded several interesting results. We have exposed a large number of CM students to AutoDesk Revit, and this has already begun to break down student reluctance to explore BIM. As more students gain experience with BIM, we hope this knowledge will permeate the program and the student body.

The students have also experienced what happens when the design is incomplete or key details are missing. Incomplete drawings mean frequent RFI's that must be resolved before the team can move on to other design tasks. This is frustrating for students who are used to starting and finishing tasks as quickly as possible.

Due to the phasing of the C4P program, project design team students (300L) have not had the experience of building the modules that they are designing. Interestingly, this has highlighted many of the communication disconnects that can occur between designers and builders. As the C4P program is fully phased-in, both project design and project management teams will have the practical experience of constructing their mock-ups, and they will have experienced the problems associated with inadequate construction documentation and/or project management practices. We expect that this practice construction experience will improve the overall quality of design and management team output.

Future Direction

The intent of this integrated lab is to improve construction management student preparation for the profession. We are embarking on a longitudinal study of the integrated lab. Over the next few semesters, we will have cohorts of students who have experienced one, two and three iterations of the integrated lab, along with current seniors who were not required to take this lab, providing a rich data set of experiences. Our longitudinal study aims to evaluate the integrated lab by addressing the following research questions using a case study methodology (Yin, 2009):

1. What are the experiences of the CM student over the course of the integrated labs?
2. How do communication skills develop over the course of the integrated labs?
3. How does the integrated lab curriculum develop over time?

This paper provides a baseline data point for question #3. To address research questions #1 and #2, we will draw from student performance records, surveys, focus group interviews of students at the completion of each lab, and graduating senior questionnaires. To provide an external evaluation of student communication skills, we will survey selected recruiters who have a history of hiring from our program. Each semester, faculty in the CM program are required to prepare a Course Improvement Document that details the level of success in meeting course objectives and any changes made to the curriculum. These documents along with staffing and budget records will provide a picture of how the integrated lab process evolves. By collecting data over the course of six semesters, we expect to identify trends of student preparedness for the construction industry using statistical analysis of quantitative survey data and bottom-up coding and constant comparison of qualitative data (Quartaroli, 2008).

Conclusions

Construct for Practice C4P is a novel approach to meeting some of the challenges associated with educating construction professionals. This approach uses an integrated system of independent laboratories that allows students to develop skills in fabricating construction assemblies, developing digital design models and specifications, and managing groups of designers and builders. The integrated experience also allows students to develop skills in teaming, collaboration, and communication that are so essential to modern construction management. While the approach is in its infancy, we have developed a longitudinal strategy that will allow us to measure and assess the efficacy of C4P and develop a long-term approach to improving the concept. We intend to report on these efforts as the project develops.

References

Craik, F., & Lockhart, R. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684. doi:10.1016/S0022-5371(72)80001-X

Edmonson, A. C., & Rashid, F. (2011). *Integrated Project Delivery at Autodesk, Inc.: A case study from the Harvard Business School 9-610-016*. Cambridge, MA: Harvard Business and Technical Unit.

Froyd, J. E., & Ohland, M. W. (2005). Integrated engineering curricula. *Journal of Engineering Education*, *94*(1), 147–164.

Gunderson, D. E., & Gloeckner, G. W. (2011). Superintendent competencies and attributes: First look at a national study. *ASC Proceedings of the 43nd Annual Conference*. Lincoln, Nebraska.

Hauck, A. J., & Jackson, B. J. (2005). Design and implementation of an integrated construction management curriculum. *ASC Proceedings of the 41st Annual Conference*. Cincinnati, Ohio. Retrieved from http://ascpro0.ascweb.org/archives/2005/CEUE12_5100_Hauck05.htm

Howell, G. A. (1999). What is lean construction? *Proceedings of the International Group on Lean Construction: University of California*. Berkeley, CA. Retrieved from http://www.ce.berkeley.edu/~tommelein/IGLC-7/index.html

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. New Jersey: Prentice-Hall.

Mead, S. P., & Gehrig, G. (1995). Skills for the 21st century: What constructors need to know. *ASC Proceedings of the 31st Annual Conference* (pp. 23–28). Tempe, AZ.

Mills, T. H., Auchey, F. L., & Beliveau, Y. J. (1996). The development of a vertically and horizontally integrated undergraduate building construction curriculum for the twenty-first century. *Journal of Construction Education*, *1*(1), 34–44. Retrieved from http://www.ascjournal.ascweb.org/journal/1996/no1/Vol. 1, No. 1.pdf#page=34

Quartaroli, M. T. (2008). Qualitative Data Analysis. In S. D. Lapan & M. T. Quartaroli (Eds.), *Research Essentials: An introduction to designs and practices*. San Francisco: Jossey-Bass.

Rojas, E. M., & Mukherjee, A. (2005). General-purpose situational simulation environment for construction education. *Journal of Construction Engineering and Management*, *131*(3), 319. doi:10.1061/(ASCE)0733-9364(2005)131:3(319)

Rudolph, F. (1977). *Curriculum: A history of the American undergraduate course of study since 1636*. San Francisco: Jossey-Bass.

Yin, R. K. (2009). *Case Study Research: Design and Methods* (4th ed.). Thousand Oaks, California: Sage.