



Integrated Construction Laboratory - Lessons Learned

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Abstract

In 2011, faculty at Northern Arizona University re-designed the Construction Management curriculum by disconnecting topic-specific laboratories from their associated lectures and forming a single integrated laboratory called 'Construct for Practice' (C4P) in an effort to provide students with context-rich experiences. In addition to merging the topic-specific content, the C4P laboratory is co-convened among sophomore, junior and senior levels to facilitate the incorporation of design and project management functions into the building process. The resulting laboratory is both horizontally integrated (among topics) and vertically integrated (among roles). Now, after four complete semesters of implementation, graduates of the CM program have experienced the complete cycle of the laboratory. This paper describes how the laboratory curriculum has developed over time, presenting a summary of lessons learned, costs associated with the laboratory and recommendations for replication at other institutions.

Introduction

Construction contractors require entry-level professionals who can communicate and collaborate effectively. For instance, studies indicate that good communication skills are one of the most important characteristics of an effective construction manager^{1,2}. Current project delivery methods such as design build and integrated project delivery (IPD) rely on a high degree of collaboration. The American Institute of Architects (AIA) California Council developed a definition for IPD that noted: "At a minimum ... 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"³. The adoption of lean construction techniques also emphasizes that alignment of goals and precise project communication are key factors that can lead to a reduction in waste and an improvement in project performance⁴.

The most current standards for construction management (CM) education set forth by the American Council for Construction Education (ACCE) specifically require a graduate to "understand different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process"⁵. These outcome-based standards allow construction management programs to develop learning experiences that break out of the historical model in which prescriptive requirements result in isolated courses for each skill. In 2011, the faculty at Northern Arizona University (NAU) re-designed the CM curriculum by disconnecting topic-specific laboratories from their associated lectures in an effort to form a single context-rich integrated laboratory called the Construct for Practice (C4P) program. In addition to merging topical content, the laboratory is co-convened among sophomore, junior and senior levels to allow for the incorporation of design and project management dimensions⁶. This paper looks back on two and a half years of implementation of the Construct for Practice laboratory to share lessons learned and to provide recommendations for other programs looking to try something similar.

Background

This section provides a brief context for the development of the C4P integrated laboratory at Northern Arizona University. The interested reader is directed to a paper published in the 49th ASC Annual International Conference Proceedings⁶ for more detail on its development.

In 1866, Andrew White introduced elective study at Cornell which has led to the current university structure in which students have some ability to define their own course of study⁷. Froyd and Ohland have questioned whether the resulting compartmentalized courses can support a learning environment in which student can develop knowledge across topical boundaries⁸. In construction education, such compartmentalization assumes that students can make their own connections among the different aspects of construction management⁹. An integrated curriculum is one way to address this issue.

The integrated curriculum is not a new idea, however it has not been used widely in construction education until recently. Prominent examples can be found at Virginia Tech¹⁰, Cal Poly⁹, and the University of Washington¹¹. Other groups at the University of Oklahoma, Colorado Mesa University and University of California, Fresno are also experimenting with hands-on integrated laboratories.

The CM program at Northern Arizona University has a long tradition of hands-on learning, having evolved from a vocational education program in Industrial Supervision. Prior to the current curricular redesign, the courses were highly compartmentalized including specific courses in concrete, masonry, electrical, mechanical and plumbing systems all having associated and isolated one-unit laboratories. Larger class sizes, a shift in focus toward developing more professional skills, and inadequate facilities resulted in laboratory experiences that became outdated. Using the vertically integrated curriculum approach at Virginia Tech¹⁰ as a model, an integrated laboratory emerged that combined hands-on construction experiences with practice in design, building information management (BIM) and project management. The vertically integrated approach allowed for the co-convening of lab sections among sophomores, juniors and seniors. This allows students at different places in their construction education to take on different roles, experience a project from different perspectives, and share their expertise with their peers.

The teams in the C4P laboratory currently design, coordinate and construct an 8 foot by 8 foot mockup of a commercial building that includes concrete foundations, formwork, light gauge metal framing, waterproofing and flashing systems, masonry, acoustical ceilings and drywall. Additionally, each mockup includes basic electrical, lighting, plumbing, and ventilation systems (see Figure 1).

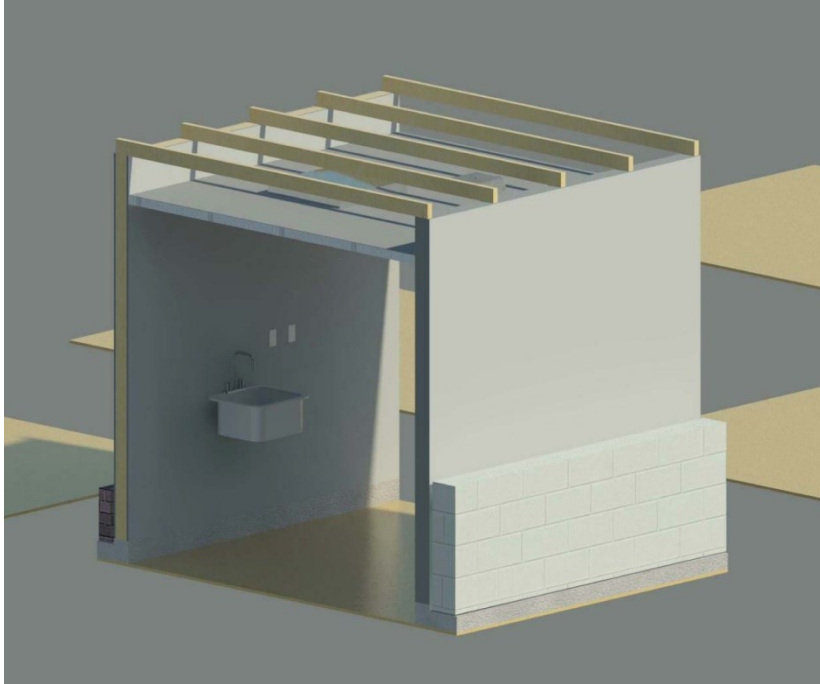


Figure 1: Revit rendering of integrated lab module

Six independent groups act as design/build ‘companies’ each semester in the C4P laboratory to complete this mockup. These companies consist of a project build team, project design team and a project management team. The roles of each experience level of students within each sub-team are as follows:

Sophomores in the CM200 Lab (“200 Lab”) section act as the **Project Build Team**, being responsible for construction of the mockups per plans and specifications. These students document progress using daily logs and resolve issues through the request for information (RFI) process

Juniors in the CM300L (“300 Lab”) section act as the **Project Design Team**, assuming the role of project architect and design engineer. They create and manage BIM models, develop construction documents, and produce shop drawings. They also respond to RFIs during the construction process.

Seniors in the CM400 Lab (“400 Lab”) section act as the **Project Management Team**, managing costs, quality and schedule. They are responsible for managing safety, mentoring members of the Project Build Team, controlling the project schedule, and interacting with the project design team.

The intended student learning outcomes for the C4P labs are to:

- Create a BIM 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, and
- Write a final report that summarizes all of the activities associated with the project and provides ideas for the improvement of future projects.

We set out to create an experiential learning environment in which groups of students would construct a small building based on a set of prescriptive requirements. We quickly realized that the small problems encountered along the way which were frustrating to both students and faculty presented important learning opportunities. Subsequently, we have made curricular decisions that embrace opportunities for students to encounter problems, experience confusion and make errors that force them to think critically.

For example, from the initial launch of the C4P program the NAU CM department lacked adequate space for this laboratory. We leased an off-campus building to serve as the “construction site” for the build (200 Lab) and project management (400 Lab) teams, keeping the design (300 Lab) teams in a computer classroom on campus, remote from the construction site. Two weeks prior to the start of the Fall 2014 semester, we lost our lease, and the C4P laboratory was moved to a new location.

This relocation created a series of realistic disruptions to the normal course of the C4P experience affecting all three levels of the design/build teams. The new lab space (or ‘site’) required substantial fit-out modification before the students could even start on constructing the lab mock-up. We took the opportunity to equate this to mobilization on a real project, and hence setup of the lab space occupied the first two weeks of the semester causing the projects to be behind schedule from the start. Additionally, the new space was oriented differently than the previous space, forcing all levels of the design/build teams to reconsider their site plans. The combination of being behind schedule and the confusion surrounding the site layout created a serious sense of frustration among many of the team members. Faculty members consciously refrained from actively solving these problems for the students. The teams eventually realized that the design, build, and project management members had to work closely together to solve the problem. The lab instructors observed a kind of “ah ha” moment amongst the students as the students realized the significance of their real-world roles and the necessity of effectively communicating with one another. This is an example of what Felder and Brent call ‘Student Centered Instruction’¹² in which sufficient structure and guidance is provided along the way to help the students achieve satisfactory performance. This allows for experiences in which students must take an active role in their own learning.

Lessons Learned

Based on our experiences over the past two and a half years, we have made modifications to the C4P laboratory in order to address shortcomings, improve efficiency and better satisfy the intended student learning outcomes. We have not, however, modified the basic goals and student learning outcomes. The following sections detail the lessons learned, and are grouped into space requirements, roles and responsibilities, document control, and tool and materials management.

Space requirements

The mock-up that we designed has a nominal footprint of 8'x8' based on standard sizes of sheet materials. Our original module layout (shown in Figure 2) provided for 6 ft. clear space between modules and a clear space around the perimeter of 6 ft. With six modules, this resulted in an area of 32'x48' for the combined site. We quickly learned that the teams started to use 'lay down' areas to construct assemblies (especially walls) away from their modules because the six-foot perimeters provided inadequate space.

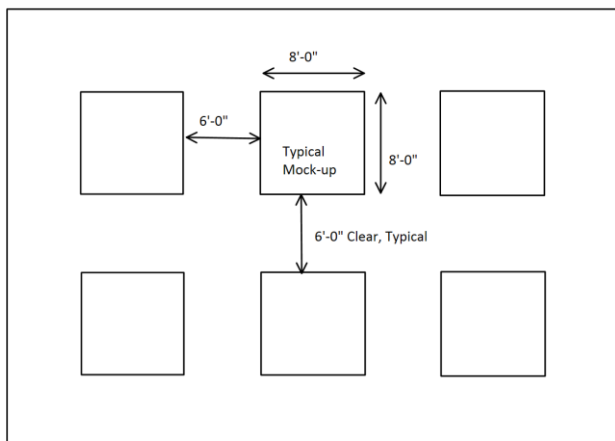


Figure 2: Original module layout

This led us to adjust the space for each team in a checkerboard fashion shown in Figure 3. Each module is provided with a 12'x24'-6" space that includes a building pad, laydown area and tool/storage area. Although the shortest clear distance in the checkerboard layout is only four feet (corner to corner), it allows adjacent teams to share laydown areas if necessary.

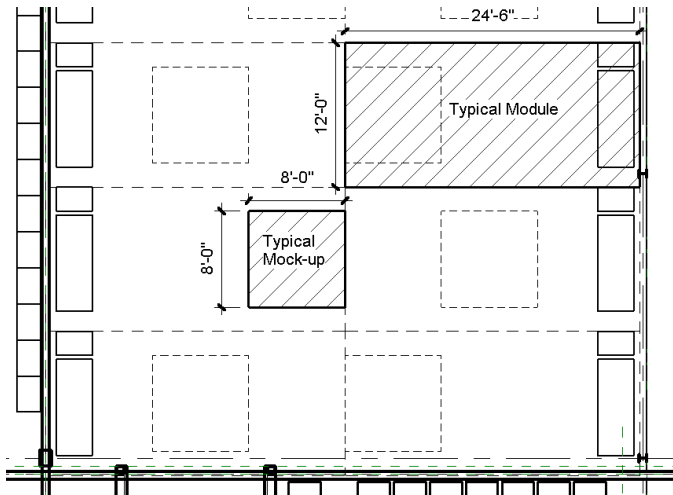


Figure 3. Checkerboard layout of lab modules

Student Collaboration among Teams

During the first two semesters, it became apparent that a disconnect existed among the three sub-teams of students within a company. There was a lack of communication that caused frustration among the students when they could not get information transmitted. To address this issue we dedicated the first session of the semester to a preconstruction meeting in order to orient the students to the lab logistics and to begin the process of having the different project participants begin to develop relationships. This resulted in improved communications among team members.

Role of Project Management Team Members (400 Lab)

In the first semester of implementation, the 400 Lab had a separate instructor from the 200 Lab. The 400 Lab concentrated on management aspects of the project that included cost, schedule and quality control while a single instructor attempted to guide the entire 200 Lab (consisting of young students, many of whom had scant practical construction experience). We quickly realized that we had a huge un-tapped resource in the 400 Lab and subsequently assigned 400 Lab students to take responsibility for mentoring their 200 Lab counterparts.

The students in 400 Lab are now working in distinct project roles as either a superintendent or a project manager. These roles rotate throughout the project so each student has the opportunity to experience each position. During a lab, the Project Managers are responsible for having an onsite meeting with one representative from the 300 Lab design team, simulating a standard weekly meeting on an actual jobsite. In these meetings the team discusses and documents drawing status, project schedule, outstanding RFIs and submittals, and any other project issues. The project managers are also responsible for taking meeting minutes and issuing any new RFIs in response to any project clarifications that are needed during the lab, along with any submittals that need approval for future lab materials. After these RFIs have been issued or answered, the project managers are required to keep track of and update an RFI and submittal log. All of these documents combine to create a project update report.

The superintendents also work in a distinct project role, with their primary responsibility being the safety of the 200 Lab students. The superintendents are also required to train the 200 Lab students on the building activity for the day. This requires the superintendents to know what task is scheduled for the day and prepare an activity-specific training plan. Students in 400 Lab have built and designed the same or a similar mockup in their previous two lab experiences. We have found this to be extremely helpful in their preparation for preparing the training plans. Superintendents are required to monitor the work on site while encouraging quality in construction. The Superintendents document all of the construction activities for a single day in a daily report.

After giving the 400 Lab students additional responsibility to train and manage the 200 Lab students, it became apparent that many of the 400 Lab students did not have the leadership skills necessary to perform these tasks. This led us to include a leadership training module at the beginning of the semester for these students to make them aware of common leadership techniques that could be beneficial in their interactions with the 200 Lab students.

In an effort to continually mirror construction industry practices within the integrated lab, a process was added to the curriculum that requires the Management team (400 Lab) students to process submittals for the materials that are used in the building of the mockup. These include product data for the concrete mix design, steel studs, drywall, densglass, mortar, plumbing supplies and electrical supplies. This process has encouraged constant communication between the 400 Lab teams and the 300 Lab teams to make sure these are completed and approved before the materials is scheduled to be installed on the mockup.

Design Team (300 Lab) Roles and Responsibilities

The Design Team (300 Lab) meets in a classroom on campus while the Project Management and Build Teams (400 and 200 Labs) meet off campus at the construction site. During the first two semesters of the integrated lab we observed that the physical distance between these two sites resulted in a real disconnect among the teams. The designers were unaware of the difficulties that were being experienced on the site. We recognized this as a very realistic situation, mirroring a typical construction project, and began to require the design team to send one representative each week to visit the site and meet with the project team. This has encouraged a higher level of collaboration among the students. In the future we are interested in exploring the possibility of transitioning to a co-located team in order to provide the students with contrasting experiences.

Balancing and Training Build Teams (200 Lab)

Initially, the Build teams (200 Lab) were comprised of randomly selected members. This resulted in some teams having much more skill and experience than others. To address this problem, students were asked to report their prior construction experience and knowledge in a survey at the beginning of the semester. The survey results were then used to place students with more construction experience in teams with students who have less experience in an effort to balance the proficiency level of all the teams.

In addition, the training of students in 200 Lab to complete a skill required more time than we expected, leaving inadequate time to practice that skill and complete the required work. We found this particularly true in the masonry and electrical trades. The solution to this problem was to shift the training outside of the lab by utilizing high-quality videos to train the students,

thus allowing them to come prepared to work at the beginning of the lab. These online training sessions are accompanied by a written assignment to assess student comprehension of the required skill. Both the 200 Lab and 400 Lab students are required to complete the online video training modules so that both the students performing the supervision and the students performing the work are trained on the proper way to complete the task.

Document Control

Managing design drawing versions, submittals, requests for information (RFIs) and other documents on a construction job is one of the primary responsibilities of the newly minted construction manager, and yet, this is one of the most difficult things to incorporate into the traditional CM curriculum. Learning this sort of process takes time and is best learned through actual experience. Because the C4P lab simulates a full project, the students are required to manage multiple documents with multiple versions, thus providing an ideal environment to experience this process. We investigated different systems in which students could track and communicate, including Prolog, Sharepoint and other cloud-based platforms. Although Prolog is one of the industry standards, its complexity and cost led us to not pursue it. Sharepoint is very powerful, but requires considerable programming and design to setup. We originally settled on EADocs because it provided the functionality of tracking design drawings, submittals, field reports and RFIs, and because the vendor provided it to us at zero cost. Although this platform is much simpler than the other options, it still required considerable setup and administrative effort. In an effort to reduce the administrative time required to setup projects, we investigated other options for document control. We currently are using Bluebeam Studio because it has become a standard used by many of our industry supporters. Students in the 400 Lab are provided a project template that shows how the file structure should be organized and are required to develop a document control system within Bluebeam. This includes creating folder hierarchy, managing permissions, developing document templates and defining a process for submitting, reviewing and tracking project documentation. This is consistent with our open-ended philosophy that guides this lab and forces the students to plan and live with their decisions.

Durability of materials

The approximate retail cost for one mock-up is \$1,962.00 as shown in Table 1, although much of this material is procured through donations (note that these costs do not include the expense of the lease on the off-campus space). The intention of this lab is to re-use as much material as possible. We wanted to provide the students with the experience of form layout, but we learned that some materials, like dimensional lumber for footing forms, did not possess adequate durability to be re-used. The 2x4 and 2x6 materials used for footing formwork tended to split when nailed and needed to be replaced each semester. To address this, we changed the formwork material to plywood that is often used by concrete construction companies for the construction of curbs and gutters. This material has proved to be much more durable and has now lasted three semesters with only minimal waste.

Table 1: Approximate costs of a single module

Fixed Costs (1 Module)	Total Cost	Reusable
Tools	\$350.00	\$350.00
Shelving/Storage	\$600.00	\$600.00
Material Costs (1 Module)		
Concrete Forms	\$65.00	\$50.00
Concrete	\$41.00	
Metal Studs	\$120.00	\$100.00
Dense Glass	\$50.00	\$25.00
Flashing	\$20.00	\$20.00
Waterproofing	\$10.00	
Brick	\$65.00	\$65.00
CMU	\$45.00	\$45.00
Mortar	\$16.00	
Plumbing	\$90.00	\$50.00
Electrical	\$130.00	\$100.00
Drywall	\$40.00	
Acoustical Ceiling	\$60.00	\$60.00
PPE (4 Students)		
Hardhat (4 Students)	\$100.00	
Safety Vest (4 Students)	\$80.00	
Safety Glasses (4 Students)	\$40.00	
Gloves (4 Students)	\$40.00	
Total:	\$1,962.00	\$1,465.00

Recommendations:

Every construction management program is unique, and as such, any experiential course should look different at each institution. For programs that chose to offer an integrated experience similar to the one described here, we offer the following general recommendations based on our experiences.

- Provide adequate space on the ‘construction site’ to allow for building, lay-down and circulation. A checkerboard pattern allows for lay-down space to be shared by adjacent teams.
- Incorporate ill-defined problems and opportunities for students to make errors and discover solutions.
- Co-mingle students of different levels into single teams and leverage the experience of the veteran students to assist with mentoring the less experienced students

- Incorporate document control into the experience, but keep the system as simple as possible
- Facilitate an environment of strong communication and get students to establish intra-team relationships early on.
- Model realistic construction situations

Future Work

We will continue to monitor the implementation of the C4P laboratory in an effort to continually improve the experience for our students. We are in the process of designing a new dedicated laboratory space on campus for the C4P laboratory and expect to discover additional areas for improvement. We are also engaged in a longitudinal study that looks at the experiences of the students who have completed this lab, specifically to determine how these experiences play into the students' construction education.

Conclusion

The C4P laboratory experience at Northern Arizona University is still relatively new and is in a state of continual evaluation and improvement. This paper provides a snap-shot of the lessons that we have learned so far and provides the interested CM program with some ideas for implementing a similar educational experience.

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