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TEACHING LEAN CONSTRUCTION FOR UNIVERSITY STUDENT(S)

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ABSTRACT

Lean construction has been considered as one of the key skills/attributes of construction management professionals. Lean educators have devised various teaching approaches and methods designed for different targeted audiences. This paper describes the Lean construction teaching approach for university graduate students. The description includes the course goal and objectives, content, and teaching-learning methods. One of the key features of the course that differentiate it from other literature in lean teaching is that it employs action learning in which the student learn how to solve a construction process problem and re-evaluate solutions they proposed. The authors of the paper consist of the instructor and previous students of the course; therefore both aspects of teaching and learning can be explored.

KEYWORDS

Lean construction, action learning, process, teaching-learning methods

INTRODUCTION

Reports on successful Lean Construction (LC) adoption emphasize that one of the important success factors is leadership and skill employed in implementation (Azevedo, Nunes and Neto, 2010; Keiser, 2012). Research also identified that educational barriers, including lack of technical skills and adequate training, as one of the great barriers to the sustainable implementation of LC (Bashir, et al., 2010; Sarhan and Fox, 2013).

When a company starts the journey of implementing LC on a construction project, several options are made available on how to mitigate the educational barriers. Common solutions are centered on relying on current employees with educational background in LC. If this option is not plausible, then the next option is to hire new personnel who have knowledge/experience or train the current employees on LC (Keiser, 2012; Hochstatter, 2013). Regardless of the available options, the industry has a legitimate expectation that graduates in architecture engineering and construction (AEC) fields will be well-versed in LC concepts and methods, as one of the latest advancements in project delivery (Johnson and Gunderson, 2009). LC has

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been recognized as one of the key attributes/skills for graduates in construction management (Ahmed, et al., 2014).

Reviewing the International Group for Lean Construction (IGLC) conference papers from 1993 to 2014 and Lean Construction Journal (LCJ) papers show limited publications on LC teaching in general, or university-based LC teaching in specific. From the existing literatures in LC teaching, educators have various approaches on how LC can be taught (Tsao, Alves and Mitropoulos, 2012). Hirota and Formoso (1998) found that in learning about LC, it is relatively straightforward for the students to understand and to apply some basic concepts like process, operation, conversion and flow activities and the general concept of waste; but it is not so easy for them to understand and comprehensively incorporate the LC principles and approaches. Therefore, exceptional learning process shared by academia and practitioners is one answer to face the challenges.

This paper describes the LC teaching approach at the School of Planning, Design and Construction (SPDC) at Michigan State University (MSU). The authors of the paper consist of the instructor and previous students of the course; so both aspects of teaching and learning can be explored. The description includes the course goal and objectives, content, and teaching-learning methods employed to demonstrate lean principles and application through different tools are elaborated. Course evaluation both from the instructor and previous students are also presented. While this paper's primary audience will be those who teach university students, it will also benefit the general diffusion of LC by sharing ideas on how to prepare future champions and practitioners of LC, as well as encourage other instructors to contribute their insights from years of teaching the subject matter.

COURSE DESCRIPTION

The course has been offered under the title "Lean Construction Principles and Methods." As the title suggests, the course solely addresses LC (Johnson and Gunderson, 2009). It is offered as a 3-credits elective graduate program course in Construction Management at the School of Planning, Design and Construction (SPDC). Since its introduction in the spring of 2002, the course has been offered every spring semester.

The course objective is to provide an understanding of LC principles and methods through reading, lectures, and discussion periods. Topics covered in the course include: Lean Production; Lean Construction principles and applications including lean design, lean assembly, lean supply, production control, lean work structuring, design of construction operations, and integrated project delivery. The course components have been evolving over the 13 years of being offered. Main reasons for this evolution are to incorporate feedbacks from the students and also to include the latest advancements in the LC community.

Most students taking the class are graduate students in Construction Management. However, there were small percentages from other majors, such as Civil Engineering, Urban Planning, Interior Design, Landscape Architecture, Business, Supply Chain, and Facility Management. Students are expected to have pre-requisite knowledge in some aspects of project management such as scheduling, estimating as well as in statistics and probabilities and also have proficiency with modern computer applications.

LEARNING OUTCOMES

The broad course outcome is focused on providing an understanding of LC principles and methods. By the end of the course, students are expected to have ability to:

1) Summarize the history and evolution of production paradigms
2) Explain and distinguish the principles of LC
3) Discuss and critique Relational Contracting methods such as Integrated Project Delivery and Integrated Lean Project Delivery
4) Use and compare lean-based productivity improvement techniques to study and improve construction operations through (a) Linear Scheduling, (b) Work Sampling and Value Stream Mapping in Construction, (c) Discrete-event computer modeling and simulation
5) Apply the Last Planner® System for production planning and control

COURSE CONTENTS AND TEACHING STRATEGIES

The course modules were designed to work together in increasing students' understanding as the semester progressed from lean theory to practical methods and applications of lean in the AEC industry. It begins with a general overview to characteristics of the construction industry focusing on the relationships among the participants and its influence on the effectiveness of construction project delivery. The instructor assigns the first chapter of Forbes and Ahmed (2011) as the required reading material to start the discussion and uses the Delta Design (Bucciarelli, 1999) simulation in the first class meeting.

This topic is followed by the concept of Lean Production principles and Lean Construction (LC) principles. It also covers characterization of project-based production systems and the AEC industry, and how these systems differ from other commonly found production systems (e.g., batch systems, linear production, and job shops), discussion of how production management systems evolved (from Taylor and Ford to Toyota) and how waste was perceived in different points in time. For this topical content, the next 3 chapters of Forbes and Ahmed (2011) are used as the background readings. At this stage also, students play the Light Simulation (a variant of the air plan game), LEAPCON Game (Sacks, Esquenazi and Goldin, 2007), Make a Card Game and Parade of Trades (Lean Construction Institute). Combined, the readings and simulations help students develop understanding of how the production system parameters are inter-related (e.g., batch size, cycle/lead time first pass yield, buffers) and how the production system in construction has evolved under LC concepts.

The course then moves forward on presenting how the LC concepts can be implemented in different areas of construction phases. Last Planner® System®, lean work structuring and construction crew designed introduced. The instructor used Chapter 5 and 6 of Forbes and Ahmed (2011) and Nerwal and Abdelhamid (2012) as reading materials. Depending on the available time, the DPR Game, the Villego Last Planner®System Simulation, or a simulated LPS® setting is conducted in the classroom. The instructor also presents case studies on lean work structuring and lean crew design. As transition to the next topic, which is integrated lean delivery (ILD), essentially the use of LC and a multi-party agreement contract, students play the "silent squares" simulation and read Schmaltz (2003) reflection on project

management against the blind men and the elephant parable. The simulation helps students understand the concept of trust boundaries, collaboration and illustrates some of the issues associated with thinking of projects as collective enterprises. The instructor then presents a Lean/IPD project from the MSU campus. Some tools used in the project such as Choosing by Advantages (CBA) (Parrish and Tommelein, 2009)and Target Value Design (TVD) (Ballard, 2012) are also presented. During these classes, students also play some team work simulations such as the Marshmallow Challenge and Win as Much as You Can. A late addition has been Dr. Zofia Rybkowski adapted TVD simulation.

The last part of the course consists of two main topics; linear scheduling and discrete event computer simulation, and how it can be used to enable LC ideals. Discussion focused on how computer simulation can be used to understanding production problems, conduct production system design by analyzing and changing system level performance metrics as opposed to local utilization factors. EZSTROBE (Martínez, 1998) is studied in detail and used as the platform for simulation.

To help students build these abilities throughout the semester, the instructor uses different type of teaching strategies besides class lectures. Most of the strategies listed in Tsao, Alves and Mitropoulos (2012), especially reading assignments and facilitated discussion, simulations, case studies, and team projects (Tsao, Alves and Mitropoulos, 2012). The class takes place once a week for three hours and 50 minutes, and each class session combined the teaching strategies accordingly. The following sections describe the different teaching strategies that were employed in this course:

Readings and Reflections

To facilitate meaningful interaction and learning, the students were assigned weekly reading assignments and required to submit two questions per book chapter and/or paper from the readings. Specific instructions were assigned to the reading assignments. Students are suggested to read the readings twice; the first time, students should get a sense of the issues and note the writers approach to them, and in the second reading , students should highlight key ideas/claims the author makes, how each is supported, relevance of ideas to construction and finally implications and potential actions.. This task will facilitate students learning in critical thinking building and writing skills. Students are required to submit their reflections a day before the scheduled class meeting. This arrangement will give the instructor opportunity to assess their understanding and prepare materials that need to be focused/emphasized in the next day class.

Facilitated Class Discussion

Students' critical thoughts and questions based on the readings are discussed at the beginning of each class. The discussion gave students the opportunity to express their thoughts and ideas, listen to others, and learn collectively. It was expected that this activity will increase their understanding on the reading material. The instructor facilitates the discussion and provides insight and direction as necessary. In some cases, the instructor may find a pattern in the questions reflecting a misperception or a misunderstanding of a particular concept. This can be addressed in the class time by a focused discussion on the topic through a more instructor-led process. For example, it is frequently a theme that students will consider that Lean Construction is a 'spin-off' from Toyota's lean methods. The instructor may find it worthwhile to address

this in the class and point out the shared pedigree and also the distinct unique aspects that separate LC from Lean Production.

*Table 1. Reading Assignments Used to Teach Specific Topic in LC**

Topic	Reading Assignments
Overview of Construction Industry	Chapter 1, 2 of Forbes and Ahmed (2011)
Lean production and LC principles	Chapter 3, 4 of Forbes and Ahmed (2011)
Lean Tools and Technique/LC application	Chapter 5, 6 of Forbes and Ahmed (2011)
Lean Integrated Project Delivery	Schmaltz (2003), Forbes and Ahmed (2011)
Computer Simulations/Operation Simulations	Paulson Jr (1994)
Linear Scheduling	Harris and Ioannou (1998)
On-site productivity data gathering and productivity improvement	Chapter 7 and 8 of Oglesby, Parker and Howell (1988)

*other paper assignments are given as appropriate

Simulations

Educational simulation has been discussed in the literature as one of tools in teaching LC (Hirota and Formoso, 1998; Izquierdo, Cerf and Gómez, 2011; Tsao, Alves and Mitropoulos, 2012). As discussed in the previous section, the course used many simulations to teach different aspects of LC. Table 2 shows the simulations and related LC concepts being taught.

Table 2. Simulation Exercises used to Teach Specific Lean Concepts

Lean Concept	Simulation Exercise / Teaching Tool
Design collaboration skills; Cross-functional teams; Product and Process Design; Set-based Design; TVD; Relational Contracting	Delta Design
Variation in Production	Parade of Trades; Dice Game
Impacts of batch size on project performance and Collaborations; Pull vs. traditional Push and Batch	LEAPCON Game; Light Fixture; Make a Card game
Last Planner® System	Villego; Last Planner® System Simulation
Pull Planning	DPR Pull Planning Simulation
Trust Boundaries and Collaboration	Silent Squares
Trust and Collaboration	Win as Much as You Can
Collaboration, Innovation, and Creativity	The Marshmallow Challenge, Ball Game, Task Switching
TVD	Adapted Marshmallow Challenge

Term Projects

The term project involves work sampling based on the work of Oglesby, Parker and Howell (1988). The project involves gathering data for on-site productivity and developing lean-based productivity improvement suggestions. Students observe

construction operations to identify value added work from non-value added work, basically looking for examples of wastes (Muda) within an actual construction project operation. Students are divided into several groups. Each team consists of 3-4 students and will collect and analyse work data from a construction site, which they are responsible to find and get access to.

The term project is presented in A3 form. The form includes general information about the project such as name and location of project, general contractor, owner, architect, start and finish dates, scope of project including number of people employed by general contractor, number of subs, number of people employed by subs, dollar value of job, major problems and unusual aspects of job, safety information, union or non- union, etc. The A3 form then outlines findings and suggested improvements. Students are also required to discuss how easy it would be to implement the suggested improvements and discuss how the improvements relate to concepts of LC.

STUDENTS' EVALUATION ON THE COURSE

This section presents course evaluations based on the students' perception. The data was compiled from the Student Instructional Rating System (SIRS) (Michigan State University, 2011) which is independently administered and managed by Michigan State University and an anonymous survey managed by the first author of the paper. The SIRS collects feedback from students in all courses to provide faculty and teaching units with feedback on their instructional. SIRS forms are provided to students at the end of the semester either in paper format or as is currently through an online format. For each question in the survey, students are asked to evaluate the course based on categories of Superior (S), Above Average (AA), Average (A), Below Average (BA), or Inferior (I). The survey targeted graduates who took the course and presently are professionals who work within the AEC industry. Besides seeking information related to the course content and the teaching method, the survey also sought information about how the knowledge gained from the course is being used and how it contributed to their career. There are 93 respondents to the SIRS and 17 respondents to the survey.

General Evaluation

All respondents of the SIRS and the survey found the course interesting, enjoyable, and intellectually challenging at the same time.

As mentioned earlier, the course is an elective course. However, the respondents consider that it would be beneficial for all construction management students to have opportunity to take this course and it should be included as a compulsory course for master student in Construction Management major. Figure 1 shows the general student evaluation on different aspects of the course, including:

a) **Student interest**: constructed from evaluation of students' interest in learning the course material, the general attentiveness in class, and the intellectual challenging remark of the course.

b) **Instructor involvement**: constructed from evaluation of the instructors enthusiasm when presenting course material, interest in teaching, use of personal experience to help get points across in class and concern with whether the students learned the material.

c) **Student-Instructor interaction:** which is constructed from evaluation of the instructor's encouragement to students to express opinions, the instructor's receptiveness to new ideas and others' viewpoints, the student's opportunity to ask questions, the instructor's stimulation of class discussion.

d) **Course organization**: constructed from evaluation of the instructor's ability to relate the course concepts in a systematic manner, the ease of taking notes on the instructor's presentation, the course organization, the adequacy of the outlined direction of the course.

e) **Course demands**: constructed from evaluation of the appropriateness of the amount of material the instructor attempted to cover, the pace at which the instructor attempted to cover the material, the contribution of homework assignments to your understanding of the course materials relative to the amount of time required, the appropriateness of the difficulty of assigned reading topics.

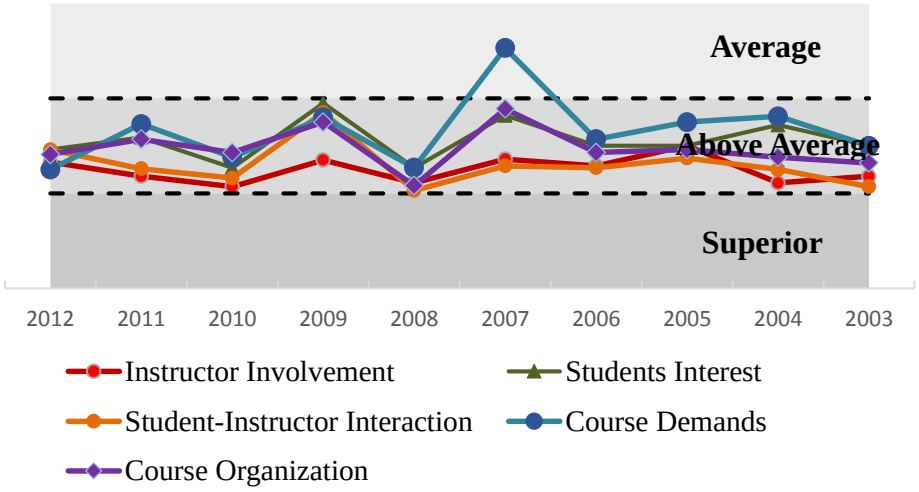

Figure 1. General Evaluation based on the SIRS

Course Contents

With the exception of some respondents who have been working the in construction industry, most of the respondents did not have prior knowledge of LC before attending the course. Therefore they value the course as an eye opener to a structured and systematic process of identifying and eliminating wastes in construction processes. The following is a quote from one of the responses:

"… The course improved my knowledge of understanding of not only LC but about the construction process in general. The course made me think deeply about how work is performed on construction projects and how it could be improved".

"The design of construction operations is something that is rarely mentioned elsewhere (in my experience) in civil engineering or construction management programs…"

Many respondents also valued the comprehensiveness of the course material especially related to balance between practical and theoretical content.

"I felt that I had a true 360 degree of the topic of (LC) after the course. The comprehensiveness of the course included discussing and analyzing LC's detractors."

However, some respondents found that the course is too intensive for a semester (Figure 1: course demands). The course content seems to be overwhelming for some

students. Contradictory, some suggested adding material on financial benefits of implementing LC.

"I wish we spent more time on the effect of LC on project financials. This would include understanding how to quantify the benefits to those "non-believers". In my career I have learned that unless you can show the fiscal benefit of an effort, it seldom will get approved / acknowledged".

Teaching and Learning Methods

In general, respondents are satisfied with the teaching and learning approach. Table 3 shows highlights of "plus" and "delta" mentioned in by the respondents.

Table 3. Plus and Delta of Teaching and Learning Methods

+	Δ
- Very well organized curriculum/syllabus and well-developed course hand-outs - The course was well laid out with very clear expectations and requirements - Varied teaching and learning methods - Group project was helpful in understanding and applying concepts - Excellent simulation/activities to demonstrate concepts and reinforcing the principles. It also kept students' interest high during the class meeting - Readings do a good job for exposing students to topic, concepts and academic/industry discourse - Class Discussions help understanding the concept better and supported a very healthy exchange of ideas - The instructors valued the students as "learning partners", which enables learning. - Lots of examples that helped understand the principles	- Instead of a one-4 hour meeting, the class should be divided into two days in a week to allow the students to absorb the material before moving on - Essential tools such as 5S, fish bone, value stream mapping were touched on. A deeper study into some of these tools would be helpful. - Having more field trips and have more industry professionals talk about live cases to increase interaction with actual contractors, consultants and owners practicing the lean way on live projects. - Perhaps it would be better to offer this course in 2 consecutive semesters, given the subject breadth and coverage

Use of the Knowledge in the Professional Works

All of the graduates who responded to the survey have been using the knowledge they gained during the class in their professional works at different level of application.

"… It is one way we differentiate ourselves in the market".

Many comments also highlighted that listing LC class as one of courses they have taken, made them stand out in their professional career.

"Taking this course definitely provided me an edge & push in the professional world. Apart from applying lean principles and practices on my projects, it gave me skills and knowledge to be part of efforts facilitating and leading lean education & training outreach within my organization as well as other construction industry organizations".

CONCLUSIONS

The course content and teaching strategies have been evolving over the 13 years of teaching it. New content is added each year to include new development in the

industry in general and in LC in particular. Improved teaching strategies have been used based on students' feedback and course evaluation.

The followings are some highlights of the course evaluation:

- Introduction to construction industry's characteristics and how it relates to productivity managements at the earlier class meeting plays an important role in providing background knowledge, especially for students outside of AEC industry.
- Variations in the teaching strategies are highly appreciated. There are two main reasons for this remark; 1) the class meeting was three hours and fifty minutes long, varied activities maintain student's attention makes the class alive and interesting, 2) Each topic in the course requires a particular teaching strategy, for example, the Parade of Trades simulation explains variation of production better that any lecture presentation can do.
- Readings and reflections assignment conducted before the class gives students the opportunity to learn before the class, help their critical thinking and at the same time give the instructor the opportunity to focus on the material that the students have challenges to understand.
- Presenting a case study in lean integrated project delivery provides a comprehensive example of LC implementation. Many students claimed that the presentation has provided them with knowledge on IPD better than reading several articles on different aspects of IPD.
- The term project give benefits in providing opportunity for students to have hands-on exposure to construction operations and to exercise critical thought about productivity improvement using systems thinking.
- Informal correspondences with some of CM program graduates confirmed that knowledge they learned during the LC class has significantly contributed to their career success.

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