CORE
Metadata, citation and similar papers at core.ac.uk
Provided by Texas A&M Repository

TEACHING LEAN CONSTRUCTION – PERSPECTIVES ON THEORY AND PRACTICE

Cynthia C.Y. Tsao[1], Marcelo Azambuja[2], Farook R. Hamzeh[3], Cindy Menches[4] and Zofia K. Rybkowski[5]

ABSTRACT

This paper builds on the IGLC paper, "Different Perspectives on Teaching Lean Construction," presented last year by Tsao et al. that documented teaching approaches from three different Lean Construction (LC) university course offerings. It aggregated the approaches taken by the course offerings, the Lean Construction Institute (LCI), and the Associated General Contractors of America to develop recommendations for learning modules, outcomes, and strategies for an introductory LC university course.

This paper provides four additional distinct perspectives to continue the conversation about teaching LC in a university setting. It illustrates the authors' differences in teaching approaches, experiences, and lessons learned from course offerings in the United States and Lebanon. The paper offers additional ideas for providing "proof of concept" to students and further illustrates how teaching LC effectively requires a combination of readings, lectures, discussions, simulation exercises, field trips, and guest speakers to mix theory with action. The paper then aggregates seven teaching perspectives in a single table to provide an overview of different approaches for teaching an introductory university-level course on LC.

KEYWORDS

University Teaching, Syllabus Design, Instruction Structure, Action Learning, Lessons Learned, Proof of Concept

INTRODUCTION AND METHODOLOGY

Lean educators are moving away from traditional course delivery methods that focus primarily on lectures and testing to more interactive methods that promote critical thinking and discussion between educators and students. Tsao et al. (2012) presented three different perspectives on teaching Lean Construction (LC) in a university setting. This study shares with the LC community four more approaches to university course delivery that cater to different learning methods to help document best practices that are emerging in LC education.

[1] Owner, Navilean, Brookline, MA, 02445, USA, Phone +1 510/593-4884, research@navilean.com
[2] Assistant Professor, Dept. of Construction, Southern Illinois University, Edwardsville, IL, 62026, USA, Phone +1 618/650-3845, mazambu@siue.edu
[3] Assistant Professor, Dept. of Civil and Environmental Engineering, 406E Bechtel, American University of Beirut, Riad El Solh-Beirut 1107 2020, Lebanon, fh35@aub.edu.lb
[4] Assistant Professor, Dept. of Civil, Arch. and Env. Eng., Illinois Inst. of Tech., Chicago, IL, 60616-3793, USA, Phone +1 312/567-3630, cmenches@iit.edu
[5] Assistant Professor, Dept. of Construction Science, College of Architecture, Texas A&M Univ., College Station, TX, USA, Phone +1 (979) 845-4354, zrybkowski@tamu.edu

The methodology employed involves surveying different teaching methods used by four LC educators in different institutions and countries. This paper concludes with a comparison of course conditions, grading methods, reading assignments, and simulations not to find the best method for teaching LC but rather to demonstrate the variety of approaches to LC education.

INDIVIDUAL EXPERIENCES IN TEACHING LEAN CONSTRUCTION

SOUTHERN ILLINOIS UNIV. (SIU): UNDERGRAD, 16-WEEK SEMESTER (AZAMBUJA)

Azambuja introduced LC as an SIU elective in Summer 2010 and has since offered the course every spring. Most students are Construction Management undergraduate seniors with 1-2 summer internships of experience. Some students have not learned about scheduling and contracts by the time they take this course. Furthermore, he discovered through observation and surveys that undergrads preferred hands-on activities to theoretical lectures and readings. This made course development challenging since he only had knowledge about graduate courses and there was a lack of publications describing undergraduate teaching approaches (Tsao et al. 2012). This section will describe his approach, including strategies to achieve course objectives.

The course objectives were broad. Upon class completion, students should be able to: 1) understand the theoretical basis of the Lean Project Delivery System (LPDS); 2) understand the differences between the LPDS and current practice; 3) apply lean concepts and practices to improve construction productivity; and 4) recognize the potential impacts lean may have on safety, quality, and the environment. Azambuja used most of the strategies listed in Tsao et al. (2012), especially simulations, case studies, guest speakers, and team projects to overcome the challenges listed earlier. Azambuja's goal was to present as many practical examples of LC as possible and to help inexperienced students visualize lean principles through simulations.

On the first day, students played the Airplane Game (Visionary Products 2008) without any lean knowledge or the potential benefits of different production system configurations. Then, Azambuja introduced a list of lean concepts to set the tone for the entire semester. Impressed with the simulation's results, students became eager to learn more about lean and always listed the Airplane Game as the most positive course experience in their course evaluations. Then, Azambuja required them to visit the glossary on the LCI website to identify all concepts addressed by the Airplane Game. In addition, within the first two weeks, he also introduced the Toyota Production System and Toyota Way principles (Liker 2003). In the absence of theoretical readings, he instead encouraged students to participate in class discussions.

Next, Azambuja presented the LPDS followed by a brief history of LC and the IGLC. He reviewed all IGLC themes and several papers posted on the IGLC website. Then, after reviewing all course topics, he discussed in greater detail about lean in the AEC industry starting with the concept of waste and the Transformation-Flow-Value Generation (TFV) theory of production (Koskela 2000). The students subsequently played the Leapcon game to improve their understanding of several concepts (e.g. push vs. pull, batching work, one-piece flow) and observe all the waste (e.g. WIP, rework) present in the process of building Lego apartments (Sacks et al. 2007).

Then, Azambuja provided a week-long review of the Last Planner System (LPS) so students were able to prepare a 12-week schedule, a 3-week Look-Ahead Plan

(LAP), and the first Weekly Work Plan (WWP) for their team project and all course assignments. Everyone participated in weekly meetings until the last day of the semester to track their Percent Planned Complete (PPC), conduct constraint analyses, and discuss the reasons why tasks were not completed as planned. Students also built updated LAPs and WWPs. This semester-long exercise provided the students an opportunity to gain first-hand experience with the LPS.

Azambuja also covered the following topics in this course: site data collection and report (process mapping tools, work sampling, questionnaires, how to approach site workers and managers, technologies for data collection); supply chain management (procurement, materials management, Value Stream Mapping); lean design (Target Value Design, Choosing by Advantages); information technology [Building Information Modeling (BIM), RFIDs, collaboration systems, video cameras]; safety; sustainability practices; Integrated Project Delivery (IPD); and aspects related to people, culture, and change. Azambuja usually spent one week on each topic.

Each week, students prepared a summary and two questions for a case study described in an IGLC conference paper or journal paper. Then, at the beginning of each class, select students presented on his/her assigned case study to help initiate class discussion. Every other week, Azambuja also arranged for at least one guest speaker to present case studies describing lean implementation. In the off weeks, Azambuja played online videos of lean case studies. Then, students wrote essays about their lessons learned from the guest speakers or videos. For the IPD week, Azambuja played the Radioactive Popcorn Game. This simulation compared the performance of integrated teams against traditionally assembled teams. Through the Radioactive Popcorn Game, students learned about collaboration, teamwork, integrated delivery, and rapid prototyping of production systems.

Azambuja graded students based on their participation in class discussions and LPS meetings; reading summaries/questions about case studies, guest speakers, and/or videos; individual presentations of case studies; final exam; and a team project. Each team applied the concepts and tools that they learned in class to collect and analyze site data from construction projects that were usually located on the university campus. Then, they made recommendations to improve the planning process and selected production processes.

American Univ. of Beirut (AUB): Grad Level, 16-Week Semester (Hamzeh)

Upon joining AUB's Civil and Environmental Engineering Department in 2011, Hamzeh prepared a new graduate course called CIVE 686 – "Lean Construction Methods & Applications." He worked with AUB's Academic Core for Processes and Systems (ACPS) to deliver this course in a blended format that involved online activities integrated with face-to-face class activities to increase student learning in an engaging and less stressful environment.

Hamzeh designed the course to teach students the management principles of LC, lean project delivery, mapping construction processes, measuring value in construction process flows, improvement measures for construction processes, risk analysis for construction schedules and budgets, and designing project site layouts.

Since LC epitomizes collaborative processes, integrated design, and integrated delivery practices, new methods that foster such values should also be used in LC education. Hence, Hamzeh designed CIVE 686 for delivery in a blended format to increase student engagement, raise their interest, improve writing and communication skills, and learn time management skills while using use the latest technological aids to improve teamwork and collaboration.

Accordingly, he designed course modules 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. The following sections highlight the different teaching strategies that Hamzeh employed in this course:

Readings – The first part of course readings introduced lean theory (the Toyota Way and value stream mapping) (Liker 2003), the transformation-flow-value (TFV) theory of production (Koskela 2000), and lean project delivery (definition, design, construction, and IPD). The second part addressed LC methods that improved scheduling (e.g., location-based management, line of balance), budgeting (e.g., simulation and risk analysis), constructability analyses [e.g., A3 process, Choosing By Advantages (CBA)], and site layout and logistics (e.g., BIM).

Reflection papers – Hamzeh asked students to write a weekly reflection paper on topics mentioned in class readings. He encouraged students to critique ideas mentioned in the readings and relate them to their construction experience. This helped students build critical thinking and writing skills. The course website also contained a one-page rubric that included writing and grading guidelines to help students meet the assignment's objectives.

Class discussion forums – Hamzeh asked students to post questions about class readings to the course website. Then, he used the questions as a basis for class discussion. He organized each class into a discussion panel where students expressed their ideas, listened to others, and learned collectively. The goal was to enable all participants to leave the forum with a better understanding than they brought to the table. Each student had to answer one or more questions posed by another student and contribute to the discussion whenever s/he had an idea to share. If the answers were incomplete, other students joined the discussion until the questions were fully answered. The instructor's role was to facilitate discussion and intervene only when questions were not fully answered (Hamzeh and Jacobs 2010).

Value Stream Mapping (VSM) project – Hamzeh asked students to map a construction process using VSM on a construction project in Beirut, build a future state map, and lay out a plan for implementation of the future state map. Students were able to increase the ratio of value-added time to total lead time by reducing wait time and eliminating non-value added activities.

Simulation Exercises – Simulating systems is one of the better tools available to analyze decisions and their impacts on a system. Learning in a simulated environment helps students understand how the real system behaves under real world conditions (Canizares 1997; Walters et al. 1997). Hamzeh employed many in-class simulation exercises to create a community of inquiry and learning among students, including: the Airplane Game, the Parade of Trades game, the Red-Green game, the Silent Squares game, and the Stick game. They helped students develop a more solid theoretical understanding of lean and its applications in the construction industry.

Schedule and budget risk project – Hamzeh asked students to study an actual project's schedule and budget, run risk analysis, and suggest improvements. This project exposed students to real life construction management methods and applied the theory learned in class to real life situations. Students learned how to apply location-based management, risk analysis, and simulation on actual projects and assess weakness in current project management methods.

Online discussion forums – As the most preferred assignment for students, online discussion forums engaged students with research, analysis and discussion of three main topics: 1) the theory of constraints and its applications in construction, 2) IPD and its barriers for implementation, and 3) the application of time management skills to student life. Students not only enjoyed this assignment – they excelled in researching, discussing, and commenting on the ideas of their peers. Thus, they honed their critical thinking skills in this assignment.

Student-delivered lectures – Hamzeh asked students to present on select course topics in class to improve their research, presentation, and leadership skills. In addition to learning about the assigned topics, this assignment helped students become more independent thinkers.

ILLINOIS INST. OF TECH: GRADUATE LEVEL, 16-WEEK SEMESTER (MENCHES)

The Illinois Institute of Technology (IIT) is located in Chicago, which has recently seen the adoption of LC principles and practices increase at a phenomenal rate. IIT has partnered with the LCI-Chicago Community of Practice and the Chicago Builders Association [an Associated General Contractors (AGC) Charter Chapter] to provide a curriculum to graduate-level full-time, part-time, and working professional students. In the spring of 2012, 27 students enrolled in the first course, of which 70% were male and 30% were female. Approximately half of the students (56%) attended college full time. About 33% of the students worked full time in the AEC industry and attended college part-time in the evening. The remaining 11% of the students worked part-time as interns in the AEC industry and attended college part-time.

The IIT curriculum included (1) VSM and waste elimination, (2) establishing continuous process flow, (3) pull planning, (4) impact of variability on productivity, (5) standardized work and 5S, (6) target value design, (7) IPD, (8) BIM, (9) teamwork and collaboration, and (10) plan-do-check-act and A3 reports. The class took place once a week for two hours and 40 minutes, and each class session combined a lecture, simulation exercise, and class discussion. Table 1 identifies the simulations that Menches used to teach students about Lean concepts. The following section will discuss the two simulations that received the most positive feedback from students.

Table 1: Simulation Exercises used to Teach Specific Lean Concepts

Lean Concept	Simulation Exercise / Teaching Tool
Seven Types of Waste	Pocket Card
Value Stream Mapping	VSM Game by ELSE Inc.
Continuous Process Flow	Dot Simulation Game
Pull Planning	Mock Pull Planning Session
Variation in Production	Parade of Trades Game
Built-in Quality	Poka Yoke Game by ELSE Inc.
5S	5S Numbers Game
Collaboration	Win as Much as You Can
Teamwork	Silent Squares
Problem Solving	A3 Problem Solving Template

Win As Much As You Can (WAMAYC) – Used on occasion by LCI for many years in their "Introduction to LC" workshops, the WAMAYC exercise is essentially a zero-sum game. In WAMAYC, the facilitator divides 8-person teams into sub-teams of two people each. Typically, a class may consist of four teams of eight people. The facilitator intentionally leaves the use of the word "team" undefined so that a "team" may be thought of as all eight people or as two people who work together as a sub-team. The facilitator instructs sub-teams to select "X" or "Y" to earn points during each of 10 rounds of play. Points are allocated in the following way: (1) 1 X and 3 Y's = X wins 3 points, Y's lose 1 point; (2) 2 X's and 2 Y's = X's win 2 points, Y's lose 2 points; (3) 3 X's and 1 Y = X's win 1 point, Y loses 3 points; (4) 4 X's = X's lose 1 point; (5) 4 Y's = Y's win 1 point. For scenarios 1, 2, and 3, the sum of points for all eight players will equal zero. Thus, under the first three scenarios, in order for a sub-team to win points, the other sub-teams will need to lose points. The only way for an 8-person team to accumulate points is for <u>all</u> sub-teams to select Y. Hence, sub-teams need to suppress their desire to "win as much as they can" so that the 8-person teams can accumulate positive points. Most teams made this discovery before reaching Round 5. However, if at least one sub-team continued to place its desire to "win as much as they can" ahead of winning as an 8-person team, the 8-person team will ultimately lose by the end. This unique situation caused significant hostility and frustration among the teams, thus simulating the emotions and behaviors that are prevalent on construction projects where owners, designers, and builders fail to work as a team and instead work against each other, causing losses for the entire "team" and project. In spite of experiencing tremendous frustration while playing this game, the students felt it most-closely simulated actual conditions on AEC projects and strongly urged that the game be played in future semesters.

Pull Planning – After a lecture on pull planning, Menches arranged a mock pull planning session. She assigned students to a team and also assigned a specific role for them on their team (e.g., carpenter, electrician, or plumber). Menches gave students a floor plan, a list of tasks, the time required to complete each task, a crew size, a start date, and an end date for a small project. She then instructed students to work backwards from the completion date to define the order of tasks and prepare a schedule. Teams that initially did not overlap tasks quickly discovered that they needed more time than was allocated for project completion. Hence, students (i.e., trades) needed to negotiate with each other on the most efficient overlapping of tasks. The working professional students thoroughly enjoyed the exercise, and several of them subsequently began using pull planning on their actual projects. Students that had no prior work experience commented that they were not familiar enough with construction processes to understand how to sequence the tasks. Two possible ways to address this limitation include: (1) make a traditional planning and scheduling course a prerequisite to taking the LC course, and/or (2) invite industry guests to participate in this class session and facilitate the development of the pull plan.

TEXAS A&M UNIV: UNDERGRAD/GRAD LEVEL, 16-WEEK SEMESTER (RYBKOWSKI)

Development Approach – Establishing a benchmark for effective teaching in LC is critical, but complicated by the fact that, while there is a growing body of knowledge being developed by the LC community, the "canon" of readings and skill development for students is inchoate at the present time (Tsao et al. 2012). To overcome this challenge, Rybkowski applied lean principles to the development of her LC course. To this aim, she: (a) established specific *outcome objectives* for the lean course; (b) developed a *mechanism* to ensure semester-by-semester continuous improvement of the course so that waste was continually removed and value continually added in alignment with established outcome objectives; and (c) orchestrated class periods using a lean facilitation model to ensure that a *culture of respect* prevailed at all times.

Rybkowski determined course objectives with an underlying assumption that students will likely be exposed to LC during their near-term careers as construction project managers. Thus, she structured the course to give students a deeper foundation in LC literature and its antecedents than is typically offered in industry workshops. To identify the course's current state and aspired future state, Rybkowski developed and used two paper-based tools: (1) a paired before-course and after-course self-efficacy questionnaire; and (2) an activity-specific "kaizen-feedback loop" survey. She also assumed the role of a discussion facilitator to encourage intellectual contributions of individual class members and engender a culture of respect. The first course offering in Fall 2012 adopted the following Learning Outcome Objectives:

- Understand history and development of Lean
- Understand key lean concepts
- Apply lean concepts to construction
- Develop an understanding of lean sufficient to be able to serve as a lean construction trainer in a construction organization

Reading Assignments – Rybkowski organized readings to support Learning Outcome Objective 1 and required students to write brief essays that summarized the readings, their conclusions, "lightbulb moments" while reading, remaining questions, and ideas for AEC implementation. Then, she facilitated a reading discussion around a common, rectangular table to enhance levels of conversation and exchange of ideas. Students discussed works in the following order: Gilbreth & Gilbreth 1963, Taylor 1947, Spriegel & Myers 1953, Ohno 1988, Goldratt 1986, Liker 2003, Koskela 1992, Ballard 2000, and Integrated Form of Agreement (IFOA) and IPD contract articles.

Simulations – Rybkowski interspersed readings with the simulations listed in Table 2 to achieve Learning Outcome Objective 2. She also introduced students to the following tools: fish bone diagrams (Ishikawa 1968), the Construction Industry Institute's (CII) Alignment Thermometer (CII-POTF 2003), and CBA (Suhr 1999).

Table 2 – Simulations Played During the Semester

Simulation Game	Purpose	Source	Developer of adaptation
Deming's Red bead game	Shows how organizational problems are often due to problems with the system rather than with individuals	Deming 1994	Unrevised; used original version
5S	Demonstrates the impact of 5S principles on time, morale, and QC	Drummond and Roberts 2012	Unrevised; used original version
The Airplane Game	Shows the impact of cell design, small batch-sizes (one piece flow), push versus pull, and load leveling	Visionary Products Inc. 2008	Unrevised; used original version
M/W Game	Shows that greater overall gains can be	CSB-SJU 2012	James P. Smith

Simulation Game	Purpose	Source	Developer of adaptation
	achieved when a system, rather than its parts, is optimized.		
Parade of Trades Game	Demonstrates the impact of variability on schedule and cost	Goldratt and Cox 1986; Tommelein et al. 1999	Zofia K. Rybkowski Josh Hullum James P. Smith
Target Value Design Game	Simulates the Target Value Design process	Peter Skillman (TED 2012)	Manish Munankami Aditi Kulkarni
Cocktail Napkin Game	Challenges participants to define LC succinctly using graphics	Zofia K. Rybkowski (unpublished)	--

Reflections and Guest Speakers – To achieve Learning Outcome Objective 3, Rybkowski asked students to discuss possible lean applications after each reading. Students also interacted with guest speakers from companies implementing lean. Finally, during the last portion of the course, Rybkowski discussed LC tools and methodologies such as the Last Planner System, IPD, Target Value Design, and CBA.

Student-Led Activities – To achieve Learning Outcome Objective 4, Rybkowski required groups of two to lead a discussion on a portion of Liker 2003. Students peer-reviewed each other's presentations using a grading rubric developed by Rybkowski. For their final group project, she required groups of five to develop a new game to illustrate a specific lean principle. The groups ran a first-run study of their game during a full class period (without Rybkowski present) with their classmates as test subjects. On the final presentation day, students administered their refined games for evaluation by their classmates, the instructor, and a guest instructor familiar with LC.

Final Exam – To prepare students for potential criticisms of LC, Rybkowski asked students to read and respond to Green (1999). Also, throughout the course, she graded students on their logic and analyses rigor, rather than on any personal opinions.

COMPARISON OF TEACHING APPROACHES AND FUTURE RESEARCH

Aggregating the approaches described in Tsao et al. (2012) and this paper, Table 3 on the last page compares the seven LC educators' course conditions, grading methods, reading assignments, and simulations not to find the best method for teaching LC but rather to demonstrate the variety of approaches for university teaching. Thus, future research should investigate the effectiveness of these different approaches for teaching principles that have emerged from both Lean Manufacturing and LC practice.

CONCLUSIONS

To continue the conversation about teaching LC in a university setting, this paper provided four additional perspectives that showed how LC educators are employing active-based learning methods in the classroom such as simulations and discussions. These methods have profound impact on student satisfaction and engagement. In addition, we encourage LC educators to use multiple teaching methods to cater for different student learning styles and reduce the dependence on one-way lectures. Furthermore, we have found online methods are becoming more useful in supporting classroom teaching. In closing, we hope this paper will encourage: (1) other educators to share their teaching approaches, experiences, and lessons learned to build the body of knowledge for LC education and (2) the community of LC educators to work on continuous improvement as a group process as opposed to individually.

REFERENCES

Ballard, H.G. (2000), *"Last Planner System of Production Control,"* thesis, presented to U. of Birmingham, UK, in partial fulfillment of requirements for Ph.D. degree.

Canizares, C.A. (1997). "Advantages and disadvantages of using various computer tools in electrical engineering courses." *IEEE Trans. Education,* 40(3), 166–171.

College of Saint Benedict and Saint John's University (2012). "The Red/Black Game." <http://www.cs.csbsju.edu/~lziegler/redblack.html> April 1.

Construction Industry Institute Project Organization Task Force (2003). *Project Objective Setting (RTS 12-1),* 2nd edition, Construction Industry Inst., Austin, TX.

Deming, W.E. (1994). *The New Economics for Industry, Government, Education,* second edition, MIT, Center for Advanced Engineering Study, Cambridge, MA.

Drummond, P., and Roberts, S. (2012). "The 5S Numbers Game." <http://superteams.com/files/SuperTeams5SGameHandout.pdf> (April 1, 2012).

Gilbreth F.B., Jr. and Gilbreth Carey, E. (1963). *Cheaper by the Dozen.* Thomas Y. Crowell Co., New York

Goldratt, E.M., and Cox, J. (1986). *The Goal: A Process of Ongoing Improvement.* The North River Press, Croton-on-Hudson, NY.

Green, S. (1999). "The Missing Arguments of Lean Construction." *Constr. Mgmt. & Economics,* 17, 133-137.

Hamzeh, F.R., & Jacobs, F. (2010). "Open Forum as an Active Learning Method for Teaching LC." *Proc. 5th LAI/EdNet Lean Edu. Conf.,* May 19-21, Daytona B., FL.

Ishikawa, K. (1968). "Guide to Quality Control" (Japanese): *Gemba No QC Shuho.* JUSE Press, Ltd., Tokyo.

Koskela, L. (1992). *Application of the New Production Philosophy to Construction,* Technical Report #72, CIFE, Dept. of Civil Engineering, Stanford University

Koskela, L. (2000). *An exploration towards a production theory and its application to construction.* Espoo, VTT Building Technology, VTT Publications; 408. 296 pp.

Liker, J. (2003). *The Toyota Way,* McGraw-Hill, New York, 330 pp.

Ohno, T. (1988). *Toyota Production System: Beyond Large-Scale Production.* Productivity Press, Cambridge, MA.

Sacks, R., Esquenazi, A., and Goldin, M. (2007). "Simulation of LC Management of High-rise Apartment Buildings." ASCE, *J. Constr. Eng. Mgmt.,* 133(7), 529-539.

Spriegel, W.R. and Myers, C.E., eds. (1953). *The Writings of the Gilbreths.* Richard D. Irwin, Inc., Homewood, Ill.

Suhr, J. (1999). *The Choosing By Advantages Decision-Making System.* Quorum, Westport, CN.

Taylor, F.W. (1947). *The Principles of Scientific Management.* W. W. Norton, NY.

TED. (2012) "Tom Wujec: Build a tower, build a team." <http://www.youtube.com/watch?v=H0_yKBitO8M> accessed: April 1, 2012.

Tommelein, I.D., Riley, D.R., and Howell, G.A. (1999). "Parade Game: Impact of Work Flow Variability on Trade Performance," ASCE, *JCEM,* 125(5), 304-310.

Tsao, C.C.Y., Alves, T., and Mitropoulos, P. (2012). "Different Perspectives on Teaching Lean Construciton." *Proc. IGLC-20,* July, San Diego, CA.

Visionary Products Inc. (2008). *"Lean Zone Production Methodologies: A Cellular Manufacturing Sim. for 6 to 8 Participants."* <http://www.visionaryproducts.biz/>.

Walters, B.A., Coalter, T.M., & Rasheed, A. (1997). "Sim. Games in Business Policy Courses: Is There Value for Students?" *J. of Educ. for Bus.,* Jan/Feb, 170-174.

Table 3: Seven Teaching Approaches for an Intro University-level Course on LC

OVERVIEW	**U. Cincinnati**	**Arizona State**	**San Diego St.**	**S. Illinois U.**	**Amer. U. Beir.**	**Ill. Inst. Tech**	**Texas A&M**
Instructor	Tsao	Mitropoulos	Alves	Azambuja	Hamzeh	Menches	Rybkowski
Undergrad/Grad	Both	Graduate	Graduate	Undergrad	Both	Grad	Both
Required/Elective	Both	Required	Required	Elective	Elective	Required	Elective
Enrollment	10 to 26	8 to 24	8 to 23	10 to 25	20-22	40	10 to 25
Semester/Quarter	Quarter	Semester	Semester	Semester	Semester	Semester	semester
Weeks	10 of 10	8 of 16	15 of 15	16 of 16	16 of 16	16 of 16	16 of 16
Started	2005	2004	2009	2010	2011	2012	2011
Ended	2008	2010	Continuing	Continuing	Continuing	Continuing	Continuing
Night/Day	Day	Night	Night	Day	Day	Night	Day
Guest lecturers	1 to 2	0	5	8	1 to 2	0	2-3
GRADING							
Assignments	X	X	X	X	X	X	X
Contribution	X	X	X	X	X	X	X
Discussion forums					X		
Exams	X	X	X	X	X	X	X
Field trip	Toyota						Toyota
Reflection papers	X				X		
Simulations	X	X	X	X	X		X
Team projects	X	X	X	X	X	X	X
READINGS							
Ballard 2000							Required
Factory Physics			Recommend				
Gilbreths 1963							Required
Goldratt 1992	Required	Required					Ch 13 req'd
IGLC papers		Required	Required	Required	Required		Required
Journal papers				Required	Required		Required
Koskela 1992	Required	Required	Required				Required
LCI whitepapers			Required				
Liker 2003	Required	Required	Recommend	Required	Required	Required	Required
Oglesby 1989		Required					
Taylor							Required
Womack 1991	Required	Required				Recommend	
SIMULATIONS							
5S Game							X
Airplane Game	X		X	X	X		X
Cocktail Napkin							X
Cups Game		X				X	
Delta Design	X						
Deming's Red-Bead							X
Helium Stick	X				X		
Leapcon				X		X	
Magic Tarp	X						
Maroon-White							X
Origami Game	X						
Parade Game	X	X	X	X	X	X	X
Radioactive Popcorn				X			
Silent Squares			X	X	X	X	
TVD Game							X
Win As Much As...	X				X	X	