Lean Theory and Techniques Applied to the Classroom: A Qualitative Study on "Informational One-Piece Flow" in an Undergraduate Estimating Class

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Lean theories and techniques, originally developed for application in manufacturing, are being applied and tested on construction sites across the country. To a lesser degree, those same theories and techniques are being applied, sometimes unknowingly, in classrooms across the country. This paper sets the stage for future research in the area of lean pedagogy by describing how lean theory and selected techniques might be applied to the design of a traditional undergraduate construction course to support effective learning and student development. Additionally, a preliminary study with qualitative results from the application of one specific lean technique – *one piece flow* – in a construction estimating class is provided. Student perceptions of what can be called "small batch size learning" or "informational one-piece flow" along with apparent benefits are discussed and analyzed. The results provide support for the hypothesis that lean theory and techniques can be applied to construction program course pedagogy to enhance student learning.

Key Words: Lean, One-Piece Flow, Pedagogy, Innovative Teaching Methods, Productivity Improvement

Introduction

Improving productivity has long been the goal of industry participants and their academic counterparts in many disciplines. Not surprisingly, this continuing pursuit of the elimination of waste in products and processes has been represented by a variety of "movements" over the years. In relatively recent history, productivity improvement theories have been embodied in over-arching conceptualizations such as Total Quality Management (TQM) (Deming, 1982), Six Sigma (Smith, 1991), and Lean Production, also known as the Toyota Production System (Ohno, 1988), to name a few. Prior to the advent of these generalized monikers for the war on waste, similar ideas were being developed independently of each other by innovative thinkers like Lillian Gilbreth (1914), Frederick Winslow Taylor (2004) and Eliyahu Goldratt (1986). Despite recognized differences in terminology and, in some cases, application, the general themes running through each of these conceptualizations are, at the very least, similar in nature. Shared emphases include continuous improvement through self-analysis, increased employee involvement, a general avoidance of waste associated with rework, and a focus on customer needs and wants (Ohno 1988; Ross 1993).

Each of these productivity paradigms appears to have entered the mainstream in accordance with Thomas Kuhn's general theory on the development of science (Kuhn, 2012). Kuhn suggested that "scientific revolutions" periodically occur as a result of anomalies that the extant paradigm is unable to explain. As new conceptualizations emerge, the one that is able to describe and resolve the anomaly becomes the accepted paradigm – at least until the next anomaly arises and a new revolution is needed. Lean theory constitutes a paradigm that has gained substantial ground in the construction industry over the past few years (Ballard et al., 2001; Koskela, 1992). Per Kuhn's theory, this is likely due to lean's apparent ability to resolve a variety of issues or anomalies facing the built environment. As a widely accepted model for productivity improvement and waste reduction, lean has been selected as the "scientific revolution" and paradigm utilized in this paper.

This paper sets the stage for future research in the area of lean pedagogy by describing how lean theory and selected techniques might be applied to the design of a traditional undergraduate construction course. With the overall goal being to reduce waste and increase value, it is anticipated that application of these concepts will support 1) effective learning, 2) student development and 3) achievement of stated course outcomes. To set the stage for this discussion, lean's origins in manufacturing and its spread to the construction industry and the classroom will be discussed. Additionally, a preliminary study with qualitative results from the application of one specific lean technique – *one piece flow* – in a construction estimating class is provided as preliminary data.

Lean Theory Across the Disciplines

Origins in Manufacturing

This section will not attempt to describe the historic facts and situations surrounding lean's inception and promulgation into western manufacturing, although the interested reader can find a detailed description of the same in Womack and Jones's national bestseller, "The Machine that Changed the World". Instead, this section will attempt to set the stage for application of lean principles by reviewing key concepts originally developed for productivity improvements in the field of manufacturing.

The ideas that ultimately culminated in the Toyota Production System (TPS) originated with Japanese businessman, Taiichi Ohno. In his seminal work, "Toyota Production System: Beyond Large Scale Production", Ohno defined the *Seven Wastes* that he believed to be problems in the automobile manufacturing business (Ohno, 1988). Jeffery Liker spent 20 years studying Ohno's theories and Toyota's application of them prior to writing what has arguably become the "bible" of lean theory for the Western world. In "The Toyota Way", Liker (2004, pp 28-29) defines the seven wastes as follows: 1) overproduction, 2) waiting (time on hand), 3) unnecessary transport or conveyance, 4) overprocessing or incorrect processing, 5) excess inventory, 6) unnecessary movement, and 7) defects. Many, including Liker, argue the inclusion of an 8th waste – unused employee creativity – although other recommendations have been put forth (Gibbons et al., 2012; Kidwell, 2006; Koskela, 2004). Each waste warrants attention, but Ohno himself considered *overproduction* to be the primary cause of most of the other wastes (Liker, 2004).

The elimination of these and any other form of waste is considered the heart of the TPS as it is the primary approach to removing non-value-adding operations during the production process (Liker, 2004). Ohno and the Toyota Motor Company developed various techniques to remove or at least mitigate the negative effects of the various types of waste. This removal would inherently add value to the product, process, and ultimately the customer. Womack and Jones (2010, pp 16-26) broadly categorized these techniques into five basic tenets:

1. Specify Value
2. Identify the Value Stream
3. Flow
4. Pull
5. Perfection

Since Toyota's successful implementation of Ohno's ideas realized dramatically improved productivity, quality and customer satisfaction, many other manufacturing industries have followed suit adopting lean principles as the basis for design and operation of their processes (Liker, 1997; Shah and Ward, 2003). The continued success and acceptance of lean theory encouraged adoption and application of Ohno's principles in industries other than manufacturing, two of which will be reviewed in this paper. In each case, overcoming and changing traditional practices has proven to be a time-consuming and difficult process.

Construction

Although it is still in relative infancy, the movement towards lean construction has gained considerable ground and attention in the past decade. The International Group for Lean Construction held their 22nd Annual Conference in Oslo, Norway, during July of 2014. The organizing committee boasted publication of "one hundred and twenty five papers, [with authors] from nearly thirty countries … confirming that our community is growing steadily and expanding around the globe." (Kalsaas et al., 2014, pp iii). A sister organization, the Lean Construction Institute was founded in 1997 by Glenn Ballard and Greg Howell and has continued to grow at the national level, currently claiming membership from owner organizations, design firms, contractors, and trade contractors across the United States. Perhaps most importantly, recent project requirements as put forth by owners have shown an increasing demand for lean construction know-how and application.

In a report entitled, "Application of the New Production Philosophy to Construction" which was written in 1992, Lauri Koskela theorized that despite admitted differences between manufacturing and construction, lean principles could be successfully applied to the construction project delivery process. Supporters of lean construction would assert that, as in manufacturing, lean projects are more likely to experience improved productivity, shorter schedules with reduced waste, and more effective project management through improved collaboration and planning, than projects using traditional delivery methods.

Education

As in manufacturing and construction, the leaders in the field of education continue to challenge current instructional and administrative practices in an effort to reduce waste and improve the value received by the customer (Comm and Mathaisel, 2005; Flumerfelt and Green, 2013). Naturally, lean theories have entered this discussion as a possible means by which these goals might be met. Initiatives such as Lean Thinking for Schools™ have developed to support the wider application of lean principles in K-20 education. However, the lingering tendency to rely on traditional approaches to education, despite the apparent need for reform is still a problem (Dagget and McNulty, 2005).

Studies show that lean theory has impacted education in three primary areas: 1) administrative processes, 2) as a subject matter and most recently, 3) as a method for improving the student experience in the classroom. This paper focuses on application of lean principles in the third area, but a brief review of the other two areas is included here as well.

Administrative Processes

As a process improvement theory, lean has been readily applied to administrative processes in education with positive results (Comm and Mathaisel, 2005; Hines and Lethbridge, 2008). Specifically, with the focus in higher education moving to cost reduction, application of lean principles often reduced waste, improved operational efficiency and contributed to the overall perceived sustainability of higher education (Comm and Mathaisel, 2005).

Construction Course Subject Matter

Lean has also recently become the primary subject matter for courses at a variety of construction programs across the country. Prior to its emergence as a course topic, lean theory was likely presented during project management classes as a lecture topic or by way of introductory discussion.

Another way that lean is being introduced as subject matter is by requiring students to perform class projects using lean project delivery techniques. Mississippi State University has successfully implemented a key component of lean construction, the Last Planner® System (Ballard, 2000), into their interdisciplinary studio course (Leathem, 2014). While the data from this study was preliminary in nature, Leathem concluded that the use of Last Planner® System as a model within which an interdisciplinary class project was conducted resulted in improved student development in a number of areas. Students showed improvement in the development of discipline specific knowledge and cross-disciplinary understanding, as well as improved communication skills.

Student Experience in the Classroom

What was accomplished and continues to be tested at Mississippi State University is slightly different than what is being considered in this paper. Leathem (2014) used lean principles as vehicles to assist students in the completion of a project. This paper suggests that we use lean principles to structure the design and delivery of education. In other words, the student is the product and learning is the value being added to the product, or the "output" of the educational system (see Figure 1). This approach allows the reader to view the educational process as a supply chain culminating in the delivery of a commodity (i.e., the successfully and appropriately prepared student) to the relevant customer (i.e., employers, graduate schools, etc.). This change in perspective will also allow for a direct application of lean techniques to the educational process so that suitability of each technique can be assessed.

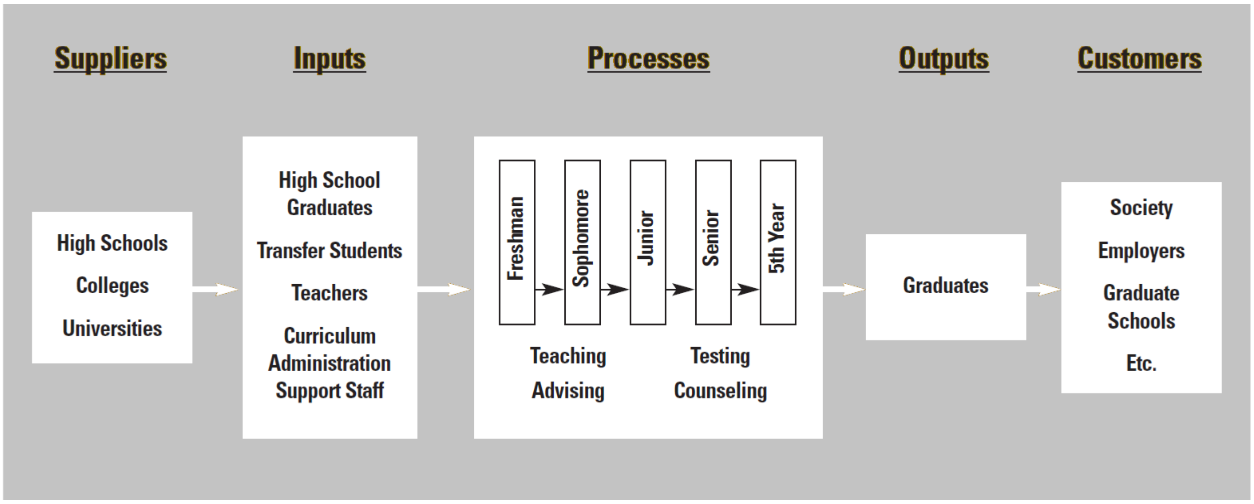

Figure 2: Educational Process (adapted from Tatikonda, 2007)

Other research supports the idea that lean principles can and very likely should be adapted for the design and delivery of education (Alagaraja, 2010; Tatikonda, 2007). Specifically, Alagaraja (2010, pp5) states:

> The age of mass consumption is coming to an end and traditional educational methods that have long adopted the stance of mass production of teaching and learning need to embrace the opportunity to solve learners' problems completely. Learners must be able to get just what they want, when they want it at an attractive price with no waste of time.

Flumerfelt and Green (2013, pp 360) suggest that lean approaches might be able to "fix the root cause of the problem in processes, rather than 'fixing' people… So then, lean could be extremely helpful for students who suffer at the hands of the shortcomings of our current educational system. The tools of lean allow stakeholders to examine the educational system closely, develop collaborative solutions and participate in continuous improvement processes."

The various shortcomings of our current educational system are due to a variety of factors. An Ishikawa diagram, also known as a Fishbone diagram, is one method used in lean to analyze root causes of problems. Using Tatikonda's (2007) cause and effect diagram as a model, Figure 2 shows possible causes of an inadequate or ineffective construction education.

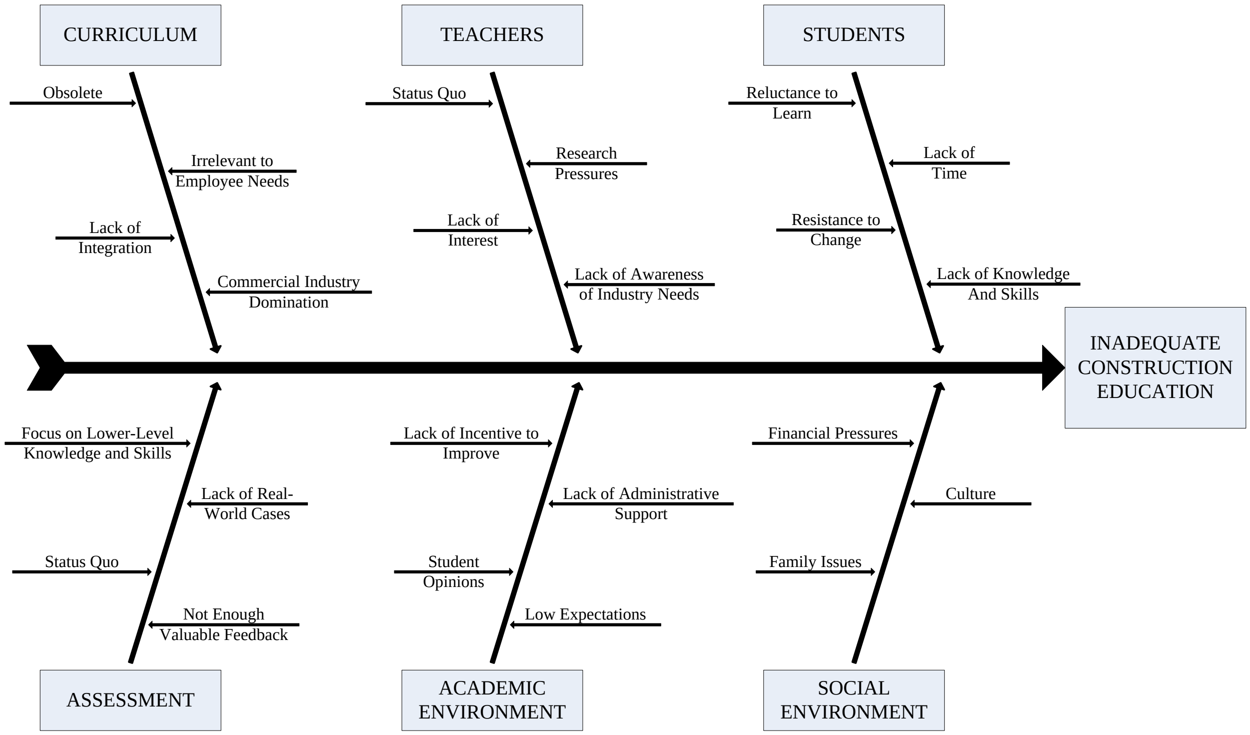

Figure 3: Ishikawa Diagram for Inadequate Const. Education (adapted from Tatikonda 2007)

The list of possible causes included in Figure 2 is undoubtedly incomplete, and not all within the control of the instructor. However, it provides a starting point for analyzing possible options for improving the final product of the educational process. Possible root causes listed above are opportunities for improvement through application of lean techniques.

Lean Pedagogy – Opportunities for Application

As suggested by Alagaraja (2010), by conceptually acknowledging learning as a customer or learner-centered process, lean theory and techniques can be applied to overcome some of the challenges faced in education. Table 1 includes a short list of lean techniques, their general description according to the LCI website glossary (LCI, 2014) or Liker (2004), and a possible construction classroom application idea. This table is not meant to be an exhaustive list of lean techniques or of possible classroom applications, but it is a starting point for additional research into the area of lean pedagogy.

Table 1
Possible classroom applications of various lean techniques

	Lean Technique	General Description	Possible Classroom Application
1	Look Ahead Planning	• The portion of the Last Planner System that focuses on making work ready – assuring that work that should be done, can be done, aby identifying and removing constraints in advance of need.	• Daily in-class review of course schedule including upcoming assignments and assessments. Review of what information they have and what will be covered in advance of assignments.
2	*Kaizen*	• The Japanese word for continuous improvement.	• Regular course evaluations beyond the final evaluation. Give students the opportunity to provide feedback and recommendations during the course.
3	*Hansei*	• Self-reflection. Being honest about your own weakness.	• Have students perform a critical analysis of personal work using a detailed rubric. After weaknesses have been identified, have student review peer work looking for opportunities for improvement in their area of weakness.
4	Plus/Delta Review	• A continuous improvement discussion performed at the end of a meeting, project or event used to evaluate the session or activity. Two questions are asked and discussed. Plus: What produced value during the session? Delta: What could we change to improve the process or outcome?	• Following major assignments or field trips, conduct a plus/delta review to determine how the assignment or field trip could be improved for future applications.
5	Workable Backlog	• An activity or assignment that is ready to be performed, but is not assigned to be performed during the active week in the Weekly Work Plan.	• Where possible, allow assignments to have bonus points for innovative ideas beyond the original scope. This can give students an opportunity to develop themselves in a semi-structured environment.
6	*Jidoka*	• Never let a defect pass into the next station.	• Immediate feedback. When possible, review assessments with students as quickly as possible. Mistakes should be immediately discussed and corrected.
7	One-Piece Flow	• Small batch sizes of product being processed to avoid inventory and obsolescence.	• Regular quizzes over smaller amounts of material instead of traditional exams.

Preliminary Study – "Informational One-Piece Flow"

The idea of "informational one-piece flow" has been tested previously under different auspices. In the literature, it has generally taken the form of comparisons between quizzes and traditional tests. Traditional instruction tends to rely on the cold cognitive model, typically in the form of high stakes testing (Flumerfelt and Green, 2013). Testing has shown in many studies to be a way to enhance learning and retention (Spitzer, 1939), however much better results with regard to learning and retention seem to be achieved when students are tested on material multiple times. McDaniel et al. (2012) provided additional insight into this issue by examining whether low-stakes testing, or quizzing, could improve overall performance. By limiting the amount of information needed for each test and conducting multiple tests prior to the final summative unit examination, they found that student performance improved between 13% and 25% overall. This concept is the impetus for "informational one-piece flow".

Students in four sections of an undergraduate construction estimating course were given nine quizzes over the course of a semester. Quizzes were administered approximately once every 10 days throughout the semester and questions were primarily taken from material discussed between each respective quiz. However, in addition to the new material, each quiz included 2-5 cumulative questions that carried over from previous quizzes. These questions were typically carried over by virtue of the fact that a substantial number of students had previously missed them. Quizzes were reviewed and graded by the students themselves immediately following completion. By limiting the amount of material needing to be recalled to a manageable amount, (i.e., a "small batch size" of information), and by providing immediate feedback to students on their performance, it was anticipated that student performance would improve along with course outcome achievement.

In a simple survey, 79 students were asked to anonymously rate whether they thought that the quizzing model of assessment helped them learn and retain course material better than traditional testing. They responded using a Likert scale (1 = strongly disagree and 5 = strongly agree). Descriptive statistics for the sample responses were as follows: average = 4.34, median = 5, standard deviation = 0.66. Anecdotal evidence from an open-ended question showed additional support for these results. While this data is admittedly preliminary in nature and by no means conclusive, it supports and encourages additional research on the topic.

Conclusions and Recommendations

As with many industries, education and the classroom environment in particular, can benefit from process improvement. Lean theories and techniques have been effectively applied in a variety of contexts and are beginning to be applied to pedagogical design and delivery. The educational system and its processes have been viewed as an opportunity for productivity improvement, similar to manufacturing and construction. This paper has provided some context and ideas for the continued implementation of lean pedagogy and also provided some data supporting continued research on the topic. It is recommended that additional applications of lean techniques to pedagogical design be considered and studied. More specifically, as suggested by Burgett (2014, pp 7), it is believed that more frequent testing or quizzing alongside immediate feedback will help reduce the "backlog of undigested concepts" that students are trying to process. This "informational one-piece flow" seems to result in more effective learning and improved student development through the educational process.

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