AC 2010-2016: THE VALUE OF INQUIRY IN TEACHING LEAN PROCESS DESIGN

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The Value of Inquiry in Teaching Lean Process Design

Abstract

Lean principles provide systematic guidelines for designing effective processes, focusing on eliminating waste by specifying value, simplifying flow, and pulling from customer demand. Lean ideas have transformed process design and significantly improved lead times, quality and cost for many manufacturing companies. While lean principles are simply stated, the design process is complicated because every process has unique constraints and competitive drivers. In this paper, we examine the issue of how to use hands-on materials to teach lean design, and in particular, the value of inquiry and the use of multiple methods within the same course. We examine these issues in the context a physical process simulation, and discuss the use of case studies and a short game about variability to explore how different approaches to teaching lean topics build depth of understanding. We present preliminary results of the effects on student learning across implementations at five universities.

Introduction

Industrial engineers are often responsible for the design/redesign of operational processes[7]; this practice continues to be driven by the use of lean principles in diverse industries. These principles provide broad guidelines for designing effective processes, in particular, eliminating waste by specifying value, making processes flow, and pulling from customer demand[12]. To apply these principles, industrial engineers use particular tactics, such as kanbans and cellular layouts, in their process designs. As in other engineering fields, such design is an art combined with science, as it can be challenging to determine which tactics to use and which wastes to reduce or eliminate given broader system constraints.

In recent years, faculty at a number of universities have used hands-on approaches for teaching lean principles, particularly physical simulations, to give students an opportunity to practice application and to engage them in actively learning lean topics[1,5,8]. In these activities, students typically simulate a process that is poorly structured and performs badly, then use specific lean tactics to improve performance, often in multiple improvement rounds. Such simulations are effective in providing opportunities for practice and decision-making, but are more controlled in terms of content and time than projects done at company sites, for example[2]. When lean simulations are used, students' abilities to apply lean ideas have improved, as well as their confidence in those abilities[5, 8]. Simulations also provide faculty to explore 'real-life' lessons about process improvement and design[5]. These results are consistent with other studies that show students' design and problem-solving abilities are improved in courses that use active and collaborative learning[11].

While the value of using such simulations and hands-on activities has been demonstrated, an interesting question is how to use such materials most effectively to teach lean process design and decision-making. The author has been using a lean simulation as the foundation of a laboratory in an introductory industrial and operations course at Worcester Polytechnic Institute (WPI) for over five years. In this simulation, students work as a group to assemble clocks in a multi-stage process. The same simulation is now used at a diverse set of universities, both in engineering and management programs, and the work presented in this paper is part of a larger study to examine how such materials can best be used and sustained over time. One area of interest is how much student inquiry it is valuable to promote when using the simulation; for example, students can be directed to make specific improvements or allowed to freely generate improvements. A second issue is the value of using complementary materials, such as case studies, which give students additional contexts in which to think about lean application. We explore these questions in this paper and present preliminary results.

Simulations: Inquiry versus Direction

The physical simulation that we use involves participants in assembling clocks in a high-volume, low-variety environment, using a multi-stage process. Each simulation is carried out in a large group of 15-20 people, with each person assigned a different role. In addition to assembly personnel, participants take on the roles of production planners, material handlers, quality inspectors, warehouse clerks, inspectors, suppliers, and customers. One round of the simulation takes approximately 15 minutes, and corresponds to a work shift. The simulation is carried out in a series of rounds; after each round, participants make improvements to the process and play again to test their solutions. The first round corresponds to a facility with a poor layout, large batch sizes, a disconnect between forecasts and customer orders, confusing work instructions, unbalanced capacity, and a poor understanding of quality drivers. A second round focuses on value and improving flow, by creating a better layout, reducing lot sizes, and re-balancing work load. A final round is used to explore demand pull.

This physical simulation has been implemented in engineering courses at several universities, at both introductory undergraduate and more advanced levels. In this paper, we focus on results across five different universities, and examine the question of how the simulation is used and the effect on student learning. Faculty at all five universities use the simulation as described above, in three rounds, with each round addressing approximately the same issues. The implementations differ broadly however, in the amount of inquiry that students are engaged in as they generate improvements. At Universities 1 and 2, the simulation is the foundation for the laboratory portion of the course, and is used to provide opportunities for experimentation. At Universities 3, 4, and 5, the simulation is played in a more standardized and directed way; while students generate improvement ideas they are guided to particular ideas and ways to implement them before the next round is played. To a significant degree, the amount of inquiry is driven by the time dedicated to the simulation in the course. Less inquiry is used at schools where the simulation is played during regular class time (there is not a separate lab) and at most 3 course sessions are dedicated to its use.

As an example of contrast between direction and inquiry, consider the issue of layout. Figure 1 shows a diagram of the initial process flow in the simulation. At University 1, small student teams (2-3 students) were asked to develop improvements to the initial process, then presented their designs to the class. The class as whole then developed an improved process, set up the physical simulation, and played it to observe the resulting outcomes. Figure 2 provides an example of the redesigned flow implemented by one class, which creates a circular flow and separate assembly lines for the two types of clocks produced (called blue and black). In contrast,

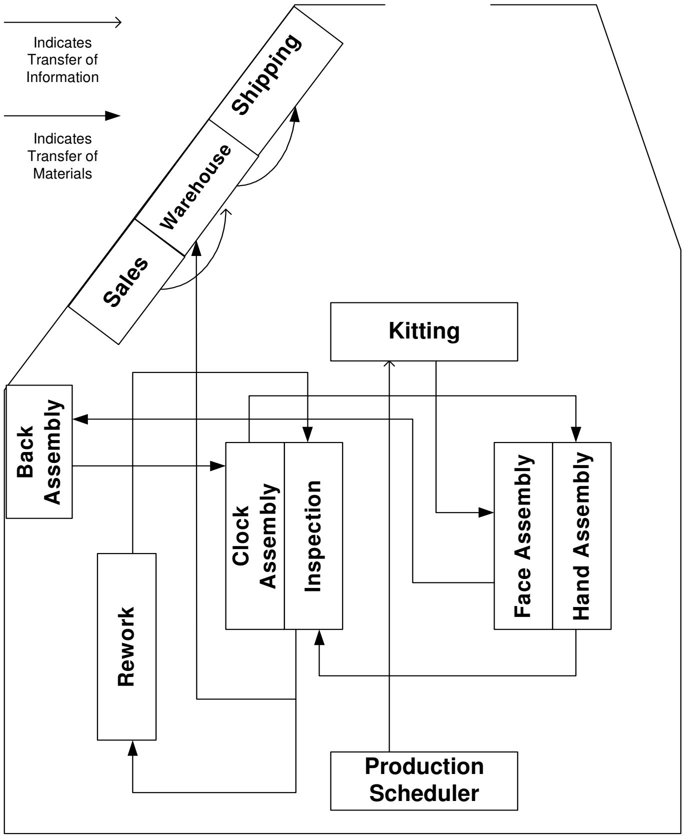

Figure 1: Initial Process Flow in the Lean Simulation

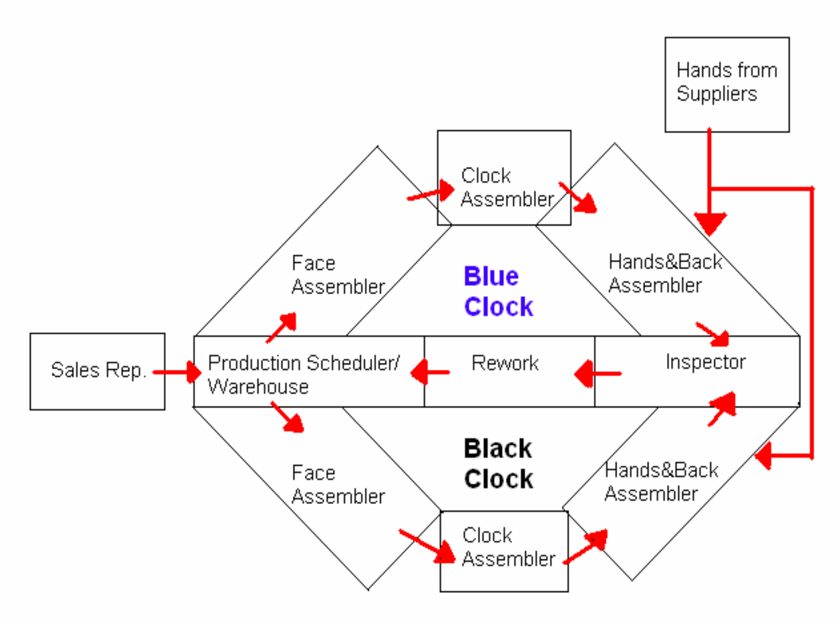

Figure 2: Layout Generated and Tested by Students at University 1

at University 5, while students generated ideas about improvement in a debrief at the end of the initial round of the simulation, the layout used in the second round of the simulation was strongly influenced by the faculty member facilitating the simulation. This 'preferred' layout is linear, rather than circular, and does not create separate lines for the two types of clocks.

While the layout shown in Figure 2 does have legitimate flaws, allowing time for inquiry permits discussion and exploration of topics that might otherwise not be clear or considered by students. The layout in Figure 2 reflects students' understanding that lean involves creating 'cells' (so an assembly line is needed for each product) and a 'u-shaped' flow. In this case, because the process used to create blue and black clocks is identical, separate lines are not that useful (and in fact, cause an issue when a new product line is introduced as a surprise in the last round). The layout generates a specific discussion of whether or not such focus is necessary, engaging students and developing the opportunity for a deeper understanding of lean ideas. In addition, in developing a circular flow, students also created some congestion.

While the inquiry focus leads to rich class discussions, it requires more time and may also lead to confusion because students' suggestions are sometimes unpredictable and unanticipated. In our study, we are seeking to examine the effects that such inquiry might have on student learning.

Complementary Hands-On Learning Activities

The lean simulation we use is effective for teaching basic lean ideas, but as a single process, cannot be used to explore every interesting complexity. We are also exploring how the use of complementary materials, which focus on either a particular topic more deeply or lean applied in a different setting, affect student learning in the context of lean process design.

As an example of the type of materials we are exploring, at University 1, faculty members use a short game with dice and pennies to explore the effects of variability on WIP, throughput, and lead time, providing an illustration of Little's Law. The game is part of the curriculum of the Lean Academy[3]. Students work in groups of 5-6, with each student operating a stage in a system that processes pennies. Each penny is processed and moved to the next stage based on the number rolled on the dice, which simulates capacity and process time variability. Students track inventory and throughput over time, and play a second time to observe the same outcomes when variability is reduced. The dice game complements the clock simulation because the critical problem in the clock assembly process is work balance between stages; variability is small relative to process times. By using a variety of hands-on activities, which emphasize or highlight different aspects of processes and lean, we expect students to develop a deeper understanding of when particular lean tactics are appropriate.

Using a greater variety of hands-on activities, rather than a single simulation, to teach lean process design may also improve students' abilities to apply what they have learned by giving them more opportunities to practice. In our project, we are also exploring the effect that using lean case studies in conjunction with the lean simulation will have on students' ability to apply what they have learned. A particular interest is case studies that focus on non-manufacturing settings. At WPI, faculty will be using case studies that explore the use of lean in the administration of a public library and in a health care setting in the next offering of the course, to examine the effect that these additional materials have on what students learn.

Discussion and Analysis

Our assessment of student learning involves examining both behavioral outcomes, related to how student perceive their learning, and content outcomes based on evaluations of student work. To carry out this analysis, the use of the simulation at each university was broadly characterized as being more inquiry-based or more directed. Universities using an inquiry-based approach to the simulation also used more complementary hands-on materials, so in this preliminary analysis these two approaches cannot be separated.

To evaluate the effects of curriculum materials on behavioral outcomes, we developed a pre- and post-course survey that asked students to evaluate their proficiency in specific knowledge areas related to lean and process design, based on a scale similar to that used in assessing engineering design[3,4]. These surveys have been used at each of the five universities implementing the clock simulation. Results for these universities are shown in Table 1, where knowledge areas in some cases represent responses averaged across several questions. At all universities, the results support the expected hypothesis, that students rate their proficiency more highly after taking the course. There also appears to be a positive correlation with the time spent on the simulation and

Table 1: Students' Evaluation of Their Proficiency, Pre- and Post Course

Knowledge Areas	Greater Inquiry				More Directed					
	University 1 N=29		University 2 N=31		University 3 N=18		University 4 N=12		University 5 N=18	
	Pre*	Post*	Pre*	Post*	Pre*	Post*	Pre*	Post*	Pre*	Post*
Lean Principles	1.5	4.4	1.6	4.3	1.5	3.8	1.2	3.2	1	3.7
Process Analysis	1.7	4.2	1.6	4.0	1.4	3.4	0.7	2.8	1.2	3.5
Lean Tactics	1.3	4.3	1.6	4.0	1.3	3.6	0.6	2.7	1.0	3.6
Data Analysis	2.9	4.2	1.9	4.1	1.3	3.6	1.0	2.9	1.9	3.7
Problem Solving	1.3	4.4	1.3	3.1	1.3	3.0	0.7	2.0	1.7	3.1
Overall	1.6	4.3	1.6	3.9	1.4	3.5	0.9	2.7	1.2	3.6

* The scale is:

- **Level 1: Have no exposure to or knowledge of**
  (have never heard of the topic, or only in casual conversation)
- **Level 2: Have experienced or been exposed to**
  (have had some organized introduction to the topic, have had someone explain it to me)
- **Level 3: Can participate in and contribute to**
  (can participate in and contribute to a discussion about the topic, or have participated in an event where the topic was used)
- **Level 4: Can understand and explain**
  (have explained the topic to someone else, prepared a presentation about the topic, or written a paper about the topic)
- **Level 5: Am skilled in the practice or implementation of**
  (have applied my knowledge in the topic by developing solutions to a case study or other academic exercise, solving a problem in an organization, or leading an activity)

inquiry within the course, with students reporting a greater gain in their proficiency the more time is spent on simulation-related activities; a correlation that we are continuing to test as more data is gathered.

Student learning content outcomes are also being evaluated, using students' work across standardized assignments and/or test questions, which have not yet been fully analyzed. We are interested in topical knowledge as well as the level of mastery, as defined by Bloom's taxonomy[6]. Rubrics and coding standards are being developed for these problems to ensure reliable assessment[9,10].

As an example, students were asked to "define lean in the context of process design". Answers were scored according to the rubric in shown in Table 2, which reports the results for the five universities. At these universities, the 'pre' responses were collected as part of a questionnaire given at the beginning of the course, which also asked students to evaluate their proficiency. At most sites, a similar post-survey was given during a class session at the end of the course. At University 5, the open-ended questions were included on an end-of-term exam. As shown in Table 2, students' ability to define lean improved at all sites, but are higher for those schools employing an inquiry approach. The scores are consistent with students' rating of their own proficiency (Table 1) in relative terms.

Table 2: Students' Ability to 'Define Lean'

Define Lean (in the context of process design)	**Greater Inquiry**				**More Directed**					
	University 1		**University 2**		**University 3**		**University 4**		**University 5**	
	Pre* N=29	**Post* N=25**	**Pre* N=31**	**Post* N=31**	**Pre* N=18**	**Post* N=18**	**Pre* N=12**	**Post* N=12**	**Pre* N=18**	**Post* N=18**
Average	0.6	2.0	0.8	1.9	0.6	1.6	0.3	1.2	0	1.6
Standard Dev.	0.9	0.6	0.3	0.8	0.3	0.7	0.5	0.6	0	0.7
Rubric:*										
0	No answer, incorrect (in the context of rubric below)									
1	Related to improvement generally									
2	Include both (1) improving a process (could state cost, quality, etc. as types of improvement) (2) understanding value or eliminating waste (can give examples of eliminating waste, rather than stating directly)									
3	Include responses above, and also describe how they are accomplished; improving flow, pull.									

Future analysis will examine scores on additional questions, as well as refine the characterization of each university's approach. The other questions used in the standard assessment ask students to provide examples of how lean principles can be applied in practice, to calculate capacity and determine the bottleneck in a process, and to calculate takt time and suggest improvements to meet it. Rubrics specific to each question are being developed. For example, the rubric for the calculating takt time considers whether students have the right information (demand related to the time available), can use the information to find the correct takt time, and can evaluate whether takt time can be achieved (by considering process capacity). As another example, when determining a bottleneck, the rubric evaluates whether students understand that the bottleneck is a resource, as well as the ability to actually calculate a value.

Conclusions

In our work, we are seeking to understand the value of inquiry within the context of hands-on simulations used to teach lean process design, as well as to explore the value of using additional materials to complement the simulation. In this paper, we provide examples of an inquiry-based approach within a lean simulation of a clock assembly process, and also provide examples of complementary activities that can be used with the simulation. We characterize the use of the lean simulation in an engineering course at five universities as being either inquiry-oriented or more directed, and explore the impact on students' evaluation of their proficiency in lean and in terms of their ability to define lean. The preliminary results suggest that greater inquiry increases students' assessment of their proficiency, as well as an improved ability to define lean.

In future analysis, we plan to characterize the use of materials at the universities more specifically, to better capture differences that might occur due to inquiry and to complementary use of material. The lean clock simulation has also been implemented at approximately 10 other academic institutions, and we also plan to extend our analysis to these additional sites.

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