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Lean Lego Simulation for Active Engagement of Students in Engineering Education*

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We have developed a simulation-based hands-on approach to actively engaging students in learning lean manufacturing principles and tools. In this innovative approach, student teams assemble Lego cars with 45 components in five work stations. The purpose is to demonstrate a variety of benefits from lean production and to provide students with opportunities to improve processes through hands-on experiential learning. Quantitative and open-ended questions were developed to survey student attitudes and experience with the simulation. The results show that over 90 per cent of the students rated their overall experience as positive or highly positive.

Keywords: Lean Lego simulation; active engagement; lean manufacturing

INTRODUCTION

LEAN MANUFACTURING, OR SIMPLY LEAN, is an operational strategy fundamentally distinguished from traditional mass production [1]. It is built upon the Toyota management model that utilizes ever decreasing resources to produce a larger variety of products at increasing levels of product quality and service [2, 3]. Toyota's success is renowned and is most often attributed to its management, engineering and workforce being well trained and highly efficient in solving problems to achieve rapid and continuous improvement in its lean systems.

Over the last 15 years, the lean strategy has gained increasing interest and application in a wide variety of industries, going far beyond its initial beginnings in the automotive manufacturing sector to the aerospace, defence, communications and medical equipment-manufacturing sectors [4–6]. Lean has been employed not only at the shop-floor of large and medium-sized manufacturing enterprises but also at SMEs [7–9]. Manufacturing companies which have applied lean have typically seen cost and space reductions of over 30 per cent, inventory and throughput time reductions of well over 50 per cent, and reduction in quality defects of 50 per cent or more.

Lean manufacturing education and our innovative approach

Due to the growing needs of modern industry for students who have strong skills and deep knowledge of lean [10], lean manufacturing is taught either as a stand-alone course or as an important component in other courses in many engineering (especially industrial engineering and manufacturing engineering) and business management programs. Numerous conferences, workshops, and seminars are also held each year to address the industrial implementation of Lean as well as to educate business leaders, engineering professionals, and students on various Lean principles and tools [11].

The traditional approach to teaching lean in universities and colleges is classroom lectures, in which students passively receive information from the instructor and do not have opportunities to develop a first-hand experience of the application of lean principles and tools. To address this issue, we developed and implemented a simulation-based active learning approach over the past two years to assist the teaching of lean in our manufacturing course curriculum. As implied by its name, active learning is an instructional method that actively engages students in the learning process. It has two core elements: student activity and engagement [12]. Studies have shown numerous benefits of active learning, such as better student attitudes and improvements in their thinking [13] and engagement [14].

Our active learning approach is called Lean

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Lego Simulation (LLS) in which students are grouped into teams that compete to create the most effective production line for Lego cars over three extended class periods (called Phases I, II and III) of three hours each. Each Lego car has 45 components and is assembled in five work stations. The purpose of LLS is to show students a variety of benefits from lean production and to provide an opportunity for students to improve a process through hands-on learning. The LLS is the result of cross-disciplinary collaboration among three engineering and business faculty members and involves students from six engineering, business and education majors.

INSTRUCTIONAL OBJECTIVES

Among lean practitioners and educators, it is commonly understood that we only understand lean principles through experience, combined with reflection. Therefore, the objective of the LLS is to show students a variety of benefits from lean production and to actively engage students in a series of learning activities. This is accomplished by using the tools and techniques of lean in an experimental environment that simulates the real world; but through speeding up the process, student engagement can become more intense as well.

How does the LLS fit in our course curriculum?

Utah State University is the administrator of the premiere Shingo Prize for Operational Excellence [15]. The Shingo Prize is the only business excellence award in the world that focuses on lean techniques. Our lean course is structured to fit the basic principles from the Shingo Prize Model [15], a proven lean business model, and also serves as the basis for defining the body of knowledge for our course curriculum. We designed the core framework topics of the course in the same order as would be dictated by the Shingo Prize Model, which includes:

1) Defining expected customer results;
2) Providing appropriate leadership and culture;
3) Developing effective business systems through lean and the scientific method, including the understanding of the operation, establishing stability and standardization, and developing the pillars of the lean house that support continuous improvement such as making material flow according to customer demand, Jidoka (make no defect), the power of employee involvement, and respect for humanity;
4) Continuous improvement and learning.

The Lean Lego Simulation addresses all of the aspects of the Shingo Prize Model. The simulation is run in three phases: at the beginning (Phase I), middle (Phase II), and end (Phase III) of the semester, respectively.

Instructional objectives of the simulation

The instructional objectives of the Lean Lego Simulation are as follows:

1) Actively engage students in hands-on learning-by-doing activities;
2) Master essential lean techniques by applying lean tools to the product assembly process;
3) Improve communication skills for students and promote inter-disciplinary and cross-disciplinary collaboration in modern team-working environments.

Lean principles demonstrated in the LLS include:

- reduced inventory by improving flow,
- better throughput by designing flexible work cells,
- improved communication and worker motivation through visible systems,
- the importance of teams and appropriate teamwork processes,
- the scientific method for problem solving and learning.

All of these are focused on providing more value to the customer, which generates better results for any organization.

INNOVATION AND UNIQUENESS OF LLS

The innovation and uniqueness of our LLS approach is threefold:

1) LSS aims to provide a real-world opportunity for students to use their hands to build a 'physical' Lego car in a modern team-work environment. In this way, students get to see the process from the worker's perspective. Many other simulation activities employed in engineering education are primarily based on computer simulation [16–21] and virtual reality [22, 23] in various formats, such as multi-media and online distance education. In those simulation activities, a computer software program is used, and what students touch with their hands is a computer keyboard. On the one hand, computer simulation has numerous advantages such as the low cost of experimental set-up and the quick response to the change in input parameters. On the other hand, computer simulation meets a great challenge to simulate the people-to-people interactions that are one of the most important elements in real processes [24]. The LLS approach enables our students to experience the human side of Lean through people-to-people interactions.
2) Second, to the best of our knowledge, we are among the first group of educators who use a Lego car with more than 25 components for lean simulation. Legos have been widely used in teaching a variety of engineering courses [25–28], also there are a variety of lean simulations floating around the lean community, for ex-

ample, the paper airplane, nuts, bolts and washers, plastic pens and simple Lego assemblies typically with about 10 components. Unfortunately, just as many of the basic lean principles have been passed from sensei to students, those lean simulations have not been well documented and therefore are not readily available. Our Lego car has 45 components and involves five work stations for assembly, which is sufficiently complex to simulate real teamwork environments and thus provides students with an excellent opportunity for hands-on experiential learning.

3) Third, we design the LLS in a way that can be employed in typical university and college settings. In many industry settings, the teaching of lean using simulations can take anywhere from one to three days. There is not that much time available in the university and college setting, usually due to limited class times of only 50 to 75 minutes per class. Our Lean Lego Simulation is designed to complete within an extended three-hour class period, or, in a limited way, within 75 minutes, making it feasible for other universities to adopt it.

DETAILED PROCEDURE FOR CONDUCTING LLS

A total of 225 car kits were purchased for the simulation. The type of car, or other toy, is not important. We had 75 cars per team in order to run the simulation with three teams and for 10 to 15 minutes.

Set-up and preparation of the simulation

To start the simulation, a traditional batch flow process was established for assembling a Lego car in five work stations. Figures 1 and 2 show the Lego cars before and after assembly.

The class was divided into three teams, and each team had between seven and ten students working in five work stations on the assembly line. Each student was assigned a different role (supervisor, line worker, material handler or timekeeper/observer); 'Role Statements' sheets were given to the students before they did the simulation. Each team needed at least two material handlers. Large teams might have a supervisor and one or two observers and timekeepers.

The classroom required movable tables and chairs, rather than desks or fixed furnishing. Each team had a 'stockroom' table at the rear of the classroom, where all Lego components were placed; they were kept separate from the work line to emphasize the impact of material handling. Material handlers were required to bring parts from the stockroom (back table) to the work stations. In Phase I, material handlers were allowed to use 'forklifts' or 'tuggers', which could carry many parts. In later phases, smaller batches were used to simulate just-in-time.

Three simulation phases

LLS was run in three phases at the beginning (Phase I), middle (Phase II) and end (Phase III) of the semester. In Phase I, students became familiar with the Lego cars and the production process, and established the baselines for productivity, inventory, labor, space and output. Most importantly, students were allowed enough time to feel they were capable of doing their jobs well, otherwise improvements in later phases could be rationalized as simply learning curve effects. However, in Phase I, students had no knowledge yet of how lean principles could be applied to improve the assembly operation. In Phases II and III, students were encouraged to apply the lean concepts and tools that they had learned from the readings, lectures and class discussions to improve the assembly operation. The simulation in Phases II and III further helped students appreciate the power of the simple principles of waste elimination, standardized work and flow to significantly improve the process, even after achieving single piece flow.

Each of Phases I, II, and III involved two rounds. The purpose of Phase I was to show the students possible improvements when transforming from batch flow production to single piece flow. Of course, the fundamental improvements are significant reductions in inventory and throughput time. However, we also wanted students to experience the human elements of participation and empowerment. The second and third phases of the simulation help students

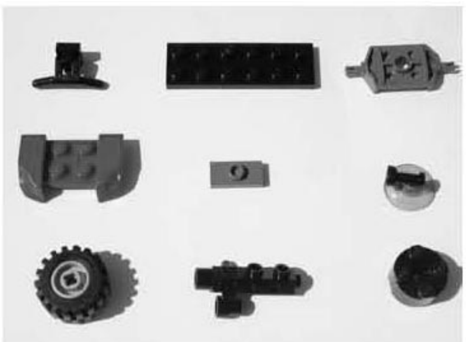

Fig. 1. Some of the 45 Lego components before assembly.

Fig. 2. Lego cars after assembly.

appreciate the power of the simple concepts of waste elimination, part presentation, standardized work and worker flexibility to significantly improve upon even single piece flow.

Phase I: round one

In round one, the line workers were allowed to practise building cars at their stations. The material handlers were able to get to know the components and how many were needed at each station. This also allowed the pipeline to fill up before starting. We usually had a five- minute practice run followed by a quick disassembly, running the line backwards to allow for plenty of parts in the full run.

Then each team was allowed to run their process for 15 minutes. To avoid end-of-game strategies, students did not know the actual length of the run. A shorter amount of time would not allow the processes to stabilize and for chronic process problems to occur. Based upon pre-timed station cycle times, the process should be able to produce two cars every minute. Detailed production and inventory records were recorded after round one.

The role statements for the team members in round one are shown in Table 1. The keys to this round are working in batches of three, and working as fast as possible because workers are paid on piece-rate.

Phase I: round two

Table 2 lists the role statements for the team members in round two. In this round, the teams

Table 1. Role statements for team members in round one

Role	Role statement
Supervisor	You are responsible for quantity and quality of output. However you are not trained as a worker in this process, so you cannot do the work. Workers see you as not knowing what they do, so you should be careful not to tell them how to do their work. You can encourage, motivate and reprimand workers in order to maximize the quantity and quality of their work.
Line worker	You are a skilled line worker who is paid by the hour, but *your bonus and job performance evaluation are heavily weighted on your output quantity*. Your job is defined and you cannot change it. You work in *batches of three*, assigned to one of the following work stations: 1. Assemble bazooka and soldier 2. Chassis Assembly steps 1–3 3. Body Assembly steps 4–6 4. Accessories Assembly steps 7–9 5. Mount tires on wheels and mount wheels on jeep You can only do one of the tasks, and you are not cross trained on any other station. A material handler will bring you the parts you need, but it is your job to sort and inspect the parts after they arrive.
Material handler	You are responsible for getting materials to the line. Central inventories are kept in the back of the room (the stockroom). You may transport the equivalent of four units of materials in one trip (for example, 16 tires and 16 wheels). You have a forklift (an $6'' \times 10''$ Tray) in which to transport material to your line. When you deliver parts to the line, you must give each station the right parts, but you are not required to organize or even separate the parts. You don't have time for that!
Timekeeper/observer	Your role is to observe the entire process in order to provide feedback to the team after the process. You should measure the total throughput time at least once in the middle of the production period. You should also measure the cycle time per unit at each station.

Table 2. Role statements for team members in round two

Role	Role statement
Team leader	Your role has changed from supervisor to team leader. You are still responsible for quantity and quality of output. You are trained as a skilled worker in this process, so you can do the work at any station. You can step in at any time, to help assure that takt time (the desired time between units of production output, synchronized to customer demand) is maintained or problems quickly resolved. You can encourage, motivate and train workers in order to assure the takt time and quality of their work.
Line worker	You are a skilled line worker who is paid by the hour. Your job is defined by standardized work, but you can work together with the team lead to change your standardized work. You work in *one piece flow*, where you work together with the team leader to design the work stations and standardized work. Cross training on other stations is encouraged. A material handler will bring you the parts you need. You should work with the material handler to make sure that parts are placed exactly where and how you need them.
Material handler	You are responsible for getting materials to the line. Central inventories are kept in the back of the room (the stockroom). You may transport the equivalent of four units of materials in one trip. You have a forklift (an $6'' \times 10''$ Tray) in which to transport material to your line. When you deliver parts to the line, you must give each station the right parts. Work with the line worker to make sure that materials are placed where and how they are needed.
Timekeeper /observer	Your role is to observe the entire process in order to provide feedback to the team after the process. You should measure the total throughput time at least once in the middle of the production period. You should also measure the cycle time per unit at each station.

were encouraged to redefine their roles and to switch to single piece flow. Teams were allowed 30 minutes to conduct a rapid improvement event to define the new process and role statements. The teams were expected to make significant changes in the material handler processes and add additional material handlers (if necessary) to assure that material shortages were eliminated. Supervisors were converted to team leaders who could help throughout the process where needed. The assembly process was not changed, other than to eliminate batches. Then, the students were allowed to run their processes for 15 minutes. It was expected that inventories would be less this time, but some stations might still have excess inventory. The teams had not focused on pull, but rather had only eliminated batching. The output was expected to jump to over 20 cars in 15 minutes.

Phases II and III

During Phases II and III, the teams were encouraged to apply the key principles of pull and flow and eliminate obvious wastes, along with all other tools and techniques learned in the course. Teams were expected to meet outside class to develop strategies and to do specific assignments. For example, students developed a work sequence chart and line balance charts. During the actual simulation, an additional 30 minutes were allowed for a rapid improvement event. Additional improvements were expected. In fact, they were startling. Each team was able to surpass 40 units in 15 minutes, and the inventory was limited to one active unit in each station. Teams created work cells that supported much better cooperation and cross-training between cells. They also improved cooperation between material handlers and the workers, establishing better methods of communicating and delivery.

ASSESSMENT OF STUDENT ATTITUDES AND EXPERIENCE

Student demographics

A total of 71 students responded to our internal assessment survey conducted in two semesters when we taught the course. Table 3, which lists student demographics, shows 80 per cent (n = 57) of the students surveyed in two semesters are male and 20 per cent (n = 14) are female. The students are from six engineering, business, and education majors at our university: Mechanical Engineering, Business Administration, Operations Management, International Business, Human Resource Management and Instructional Technology.

Table 3. Student demographics

	Semester A (n = 44)	Semester B (n = 27)	Two Semesters Total (n = 71)
Male	35	22	57
Female	9	5	14

Assessment of student attitudes and experience with the LLS

We designed a questionnaire with both quantitative and open-ended questions to survey students' attitudes and experience with the LLS. The questionnaire is shown in Table 4.

Table 5 lists the number of students who responded to the first two assessment questions included in Table 4. The collected data, shown in Table 5, are plotted in terms of percentage distributions in Figures 3 and 4. As seen from Figures 3 and 4, the percentage data are highly consistent in almost every rating category for both semesters. Of the 71 students surveyed in the two semesters, 67 students (94 per cent) rated the overall experience with LLS as positive (rating 4) or very positive (rating 5); 67 students (94 per cent) rated the design of LLS as positive (rating 4) or very positive (rating 5).

All students found the simulation fun and challenging, and the competitive nature of the simulation made it more realistic. In students' written comments on how the LLS helped improve their learning, the words most frequently used include:

- See the results
- Hands on
- Group interactions
- Prove lean does work
- The class simulation of building cars was excellent

Some typical student comments are cited as follows:

Table 4. Assessment of LLS

Number	Assessment Questions
1	Compared to other engineering/business classes, please rate your overall experience with Lean Lego Simulation: Very negative 1 2 3 4 5 Very positive
2	I would like to rate the design of Lean Lego Simulation: Low quality 1 2 3 4 5 High quality
3	Please describe to what extent did Lean Lego Simulation help with your conceptual understanding of the course content.
4	What part of Lean Lego Simulation did you like the most?
5	What part of Lean Lego Simulation did you dislike the most?
6	What part of Lean Lego Simulation could be improved?

Table 5. Number of students who responded to the first two assessment questions

Assessment questions	Rating	Semester A (n = 44)	Semester B (n = 27)	Two Semesters Total (n = 71)
Question 1	5 (very positive)	33	22	55
	4 (positive)	7	5	12
	3 (neutral)	4	0	4
	2 (negative)	0	0	0
	1 (very negative)	0	0	0
Question 2	5 (very positive)	21	14	35
	4 (positive)	21	11	32
	3 (neutral)	2	2	4
	2 (negative)	0	0	0
	1 (very negative)	0	0	0

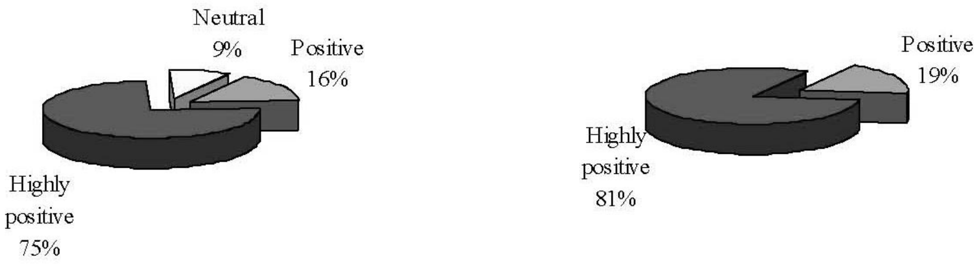

Fig. 3. Student assessment on their overall experience with LLS.

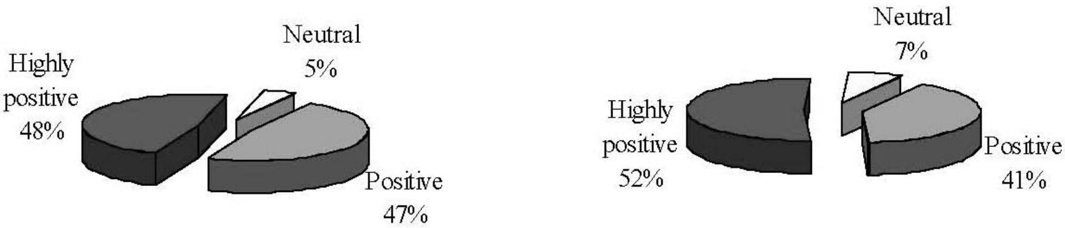

Fig. 4. Student assessment of the design of LLS.

- It sounds childish at first, but as I got into it, I learned that with a little lean implementation things can improve a lot.
- It was interesting to actually put some of the concepts that we learned into action and see how it affects our processes.
- I gained a better concept of kanban, teamwork, and especially the pull system.
- I actually see how lean manufacturing is applied in real life and how it helps the process.
- It is great hands on experience. I was able to use my knowledge and skills learned in class to actually apply them.
- It helped visualize how to use lean concepts.
- It was a good way of seeing the concepts learned in class work.
- I was actually involved in the process, which helped give me a hands-on understanding of lean. I was able to actually see the problems going on and what needed to be fixed.
- The Lego simulation really puts what we learned to life and that way you can see the changes improvements and really see the effects and be able to truce them.
- It is a visual hands-on simulation that allows me to step into a process, so reading and lecture make more sense.
- While I have worked in manufacturing for a long time, I did not know how to implement some lean ideas. This lean lego simulation helped a lot by designing a process that uses kanbans and takt time. I can visualize how to do it.

Classroom observations

Classroom observations were also made when student teams performed Lean Lego Simulation. The first observation was the importance of the people side of lean [21]. Lean manufacturing requires strong communication and team-working skills of each person involved. During Phase I, round one, there was significant confusion and poor communication among students, which resulted in a noisy environment with students yelling to and at each other. Round two was quieter. Phase II was almost peaceful, with workers proceeding at a relaxed pace with confidence and focus. Phase III was almost serene.

The second observation we made about LLS was team frustration with a supervisor who had no knowledge of the process and no interest in helping (in Phase I, round one). The teams had a strong sense of their own teamwork or lack of it. One team definitely clicked more than the other. The poor team was unanimously envious of the other teams' cultures.

The third observation was on how best to facilitate the execution of LLS. There was a need to create a clear definition of the costs of inventory (for example, some costs per component and space requirements) and to introduce some design change in the product that would display the cost of converting or scrapping all the inventory. The component costs must also be kept relative to the labour costs.

CONCLUSIONS

Recent years have seen a growing demand from industry for students who have lean knowledge and skills. The traditional approach to teaching lean in universities and colleges, however, is still classroom lectures, which present a great challenge for students to develop a first-hand experience in the application of lean principles and tools.

Our cross-disciplinary collaborative efforts over the past two years have resulted in the development and implementation of a simulation-based approach—Lean Lego Simulation—to actively engage students in the learning process. Our LLS is innovative and unique relative to others in universities and from consultants. The uniqueness of the LLS is summarized as follows:

1) First, the LLS provides an excellent opportunity for students to use their hands to build a 'physical' Lego car through team efforts and experiencing the human side of lean.
2) Second, in the LLS, a Lego car with 45 components and involving five assembly work stations is used for lean simulation, which is sufficiently complex to simulate real team-working environments.
3) Third, the LLS is particularly designed in a way that can be completed within an extended three-hour class period, which makes it feasible for other universities and colleges to easily adopt.

The scope of the assessment work performed in this study is limited to the validation of the effectiveness of the LLS in engaging students in active learning, not a detailed study on the cognitive learning process of students. That detailed study will be a future research direction that involves multi-disciplinary collaboration among engineers, business experts and education psychologists. The assessment data that we collected from two semesters show that LLS was effective in engaging students in the learning process. Through hands-on, experiential learning opportunities provided by the simulation, students experience a variety of benefits from lean production and are able to apply the lean concepts and principles they have learned in class to improve the Lego assembly process. Among the 71 students surveyed in two semesters, 67 (94 per cent) rated the overall experience with the simulation as positive or very positive, and 67 (94 per cent) rated the design of the simulation as positive or very positive. Students particularly appreciate the hands-on feature of the simulation that enables them to 'see the results' and have 'group interactions'.

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