Simulation games- An approach to teaching world class lean manufacturing techniques

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Introduction

Engineering education is essentially aimed at developing activities and facilitating students to proficiently engage in open research, conceptualisation and ideation and apply these skills to solve real engineering problems in related industries. It is necessary to engage students in the classroom environment in a manner that would aid the development of these skills to problem solving. Traditionally, representation of large-scale manufacturing facilities in a classroom environment has been addressed with pictographic information and at times, augmented by video. However, engaging students with such pictorial information is difficult and challenging as it cannot reproduce the dynamism accompanying activities in a real industrial environment. Engaging students with pictorial information are always a subject of discourse in engineering education (Fang et al. 2009, Scott et al. 2004). While pictographs can capture spatial information, the time dimension is often left unrepresented.

There are many tools and approaches that have been suggested to improve student engagement during a learning activity. It is evident that students learn efficiently in a guided environment where the lecturer facilitates as the intellectual resource for the student to gain understanding of the subject themes (Li et al. 2008), however, such an approach does not provide enough classroom engagement that would enhance learning. In order to improve the learning environment for the students of Production Engineering (3rd Level course) at the University of the Sunshine Coast (USC), several learning theories especially suited for engineering education were investigated. For example, according to Duff & Duffy (2002) and Kayes (2007) effective learning is achieved by transformation of experience. On the other hand, Yannibelli et al. (2006) and Tseng et al. (2008) emphasised on computer-based training to improve the learning environment. Problem-based learning (PBL) has been suggested (Alkhasawneh et al. 2008) as an effective way of improving engagement in engineering education. However, PBL can only be applicable in early phases of Engineering and does not reflect the professional work of engineers (Perrenet et al. 2000). Simulation-based learning (SBL) is thought (Tait,1994) be a method that enthuse students and encourage them to learn and therefore may increase engagement with learning activities.

The present generation of students have grown up in an environment of digital gaming, virtual reality simulation and augmented visualization. Thus, SBL along with traditional learning approach seems appropriate to engage learners in developing enhanced learning and professional skills (Tait 1994). The benefits of SBL include: close approximation of reality (Moratis et al. 2006), multidisciplinary team training facilities (Nishisaki et al. 2007). SBL also improves actual operational performance (Davidovitch et al. 2006) and self-efficacy (Parush et al. 2002). Additionally, today's industry is requiring 'job-ready' graduates who can "hit the ground running". SBL would appear to be the most attractive and effective method of learning for students and therefore, was considered as an activity in the teaching of Production Engineering at USC.

After reflecting on the effectiveness of SBL a simulation game using LEGO blocks (not computer software-based simulation) was developed to reproduce the real-world production environment in the classroom. The intentions are to use this method to teach the essential engineering ethos of teamwork and problem-solving within a manufacturing context. The game is designed to demonstrate the application of World-class Lean manufacturing techniques including waste reduction, Just in Time (JIT) production and Single Minute Exchange of Dies (SMED).

Simulation Game as a Learning Tool

The game activity mimics the production of a product by using LEGO building blocks as the components of the product. The simulated production line progressively assembles a product as it passes through four workstations. At each station, the components (LEGO blocks) are added to the product in a set order and location, as shown in Figure 1. The simulated production facility also includes a supply store, quality assurance station and dispatch. In the game, students make decisions on component supply, storage, delivery and quality control. Special jigs and fixtures, representing production machinery, are incorporated to make the assembly more realistic. The game is conducted in three phases to represent three different production environments with a briefing and debriefing session at the start and end of each production run. At the end of the game, students document their reflections regarding their understanding of JIT, SMED and how well they think they worked together as a team.

Production Run 1

For the first production run, students were required to produce a total of 12 batches of three variants of the product (one variant of the product is shown in Figure 1), with each batch comprising 10 products. This is to be undertaken in a single work shift, simulated in a 15-minute production run. This 15-minute run further simulates real-world work environments by including two "tea-break" and a "lunch break". In this situation, an "autocratic production manager" who is only concerned about working as fast as possible and oblivious to a chaotic workplace. This includes:

- Poor product flow; (see Figure 2)
- Breakdowns in a simulated machine
- Information lagging for quality control
- Stress on speed; "Work as fast as possible"
- A messy cluttered working environment

The total production after Run 1 was only 2 batches after 15 minutes of the simulated production. Additionally, a total of 92 items were in the state of work-in-progress (WIP) which added no value to the product. The detailed WIP is shown in Table 1.

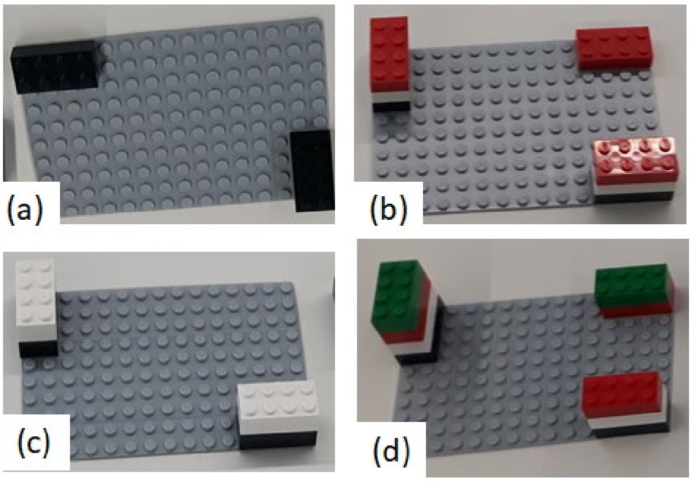

Figure 1: Simulation of product assembly (a) workstation 1, (b) workstation 2, (c) workstation 3 and (d) workstation 4 (final product).

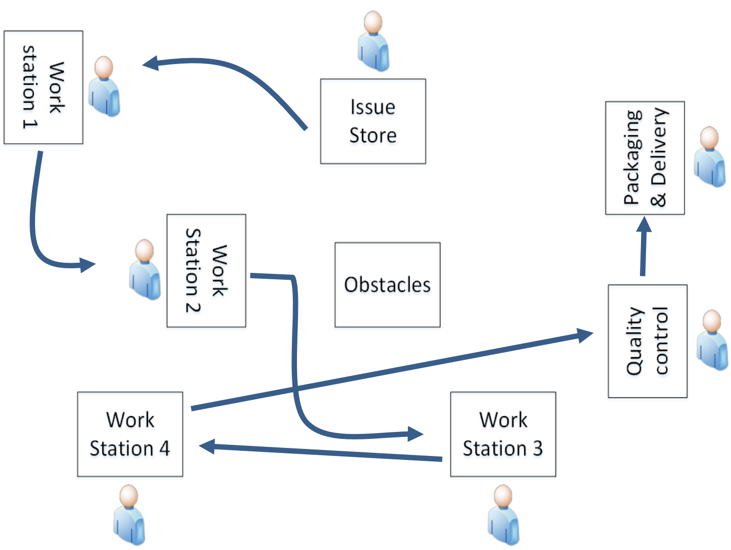

Figure 2: Schematic illustration of randomised workstations and workflow.

Learning from Production Run 1

After the completion of production run 1, students get the opportunity to work in teams to reflect on the outcomes of Run 1 and to develop strategies to improve in the next production run. A brief strategy has been explained to the student to develop a strong working group along with problem-solving methodologies including Root-Cause and SWOT analyses. At this stage students went through a brainstorming process to identify the problem, define the problem with the “5W’s + H” questions (what, where, when, who, why and how), data collection, analyse the problem and find out the best solution to the problem with monitoring strategies. Students were able to find the reason for poor performance in the production run 1 and offer a “solution” for improvement. At this point, the students were introduced to the foundation of lean philosophy which is the elimination of waste, facilitated by the use of Kanban cards. 5S theory (Sort, Set in order, Shine, Standardize, Sustain) was also introduced and the importance of tidy work-place was explained to the student.

Table 1: State of production using workstation illustrated in Figure 1

	Issue Store	Work Station 1	Work Station 2	Work Station 3	Work Station 4	Quality Control	Packaging & Delivery	Total
Quantity	20	3	26	26	5	3	9	92

Production Run 2

In this run, the character of the “manager” was flipped from -autocratic to one that encourages worker participation and input into production planning. Students are allowed to provide feedback and have control over their activities to make an effective cooperative team-based work environment. All of the students’ suggestions are discussed implemented to change the workflow for the next production run. The group implemented the plan but were only able to achieve 75% of the target (9 batches of product). Figure 3 shows the layout of the second production run, which highlights the ‘U’ cell workflow layout and the Kanban cards to regulate production.

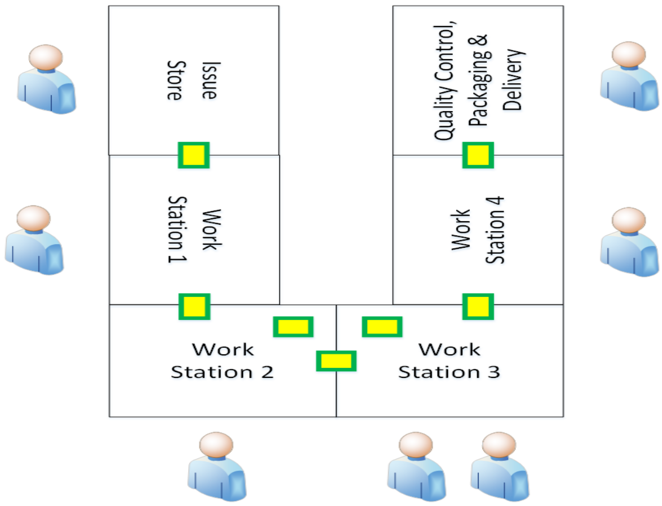

Figure 3: Illustration of Production run 2 incorporating efficient product flow, Just-in-time (Kanban) system.

After the production run 2, students got another session to identify further refinements possible to improve production and achieve the targeted production quantity. the problem and dig deep with the complex theory of production process to find out a perfect solution to achieve the target.

At the end of this run, students were introduced to the theory of SMED. The exchange of die was simulated in the game by different screw removal arrangements as illustrated in Figure 4. Figure 4a represents the non-SMED arrangement where an unnecessary long screw was used to attach the die in the block. When the die needs replacement it requires an extensive time to unscrew. Figure 4b represents a SMED arrangement where a few second is required to replace the die. Students were able to observe the effect of SMED on production as it was introduced as another variable in the simulation game.

They also experienced the hands-on understanding of the JIT theory. Students learned the use of Kanban cards to decrease the WIP and improve the production process.

Final Production Run

Final production run was developed based on student feedback from their previous experience which includes quality control, implementation of various production process theory and guideline from the supervisor or manager. It was observed that the working groups were able to create a strong team and achieve their target within the time frame. Additionally, students gained experience in World class manufacturing techniques- visual factory, slack in Kanban, Whip production, 'drum' pace setting beat of production. In visual factory, the production amount is shown in real-time everywhere in the factory. All workers are informed about the target production rate and they can monitor the progress of the production in real time (Figure 5). Students also experienced the slack in Kanban (more than one Kanban cards in workstation 2 and 3) to reduce the bottleneck problem. Students also learned the whip production where the rate of production is varied over time. To reduce the 'whip' a pace setting beat of production was introduced. The production run 3 can be summarize in Figure 6. The theory of SMED was incorporated in this run. All the students' group were able to produce the desired production in 13 minutes (less than the 15 min target). All these manufacturing techniques are difficult to teach and with the help of the simulation game students received a better understanding on these theories. Additionally, students had fun while learning.

Students gained a deeper understanding of the Lean

Figure 4: Illustrating SMED (a) non-SMED screw arrangement (b) SMED Screw arrangement

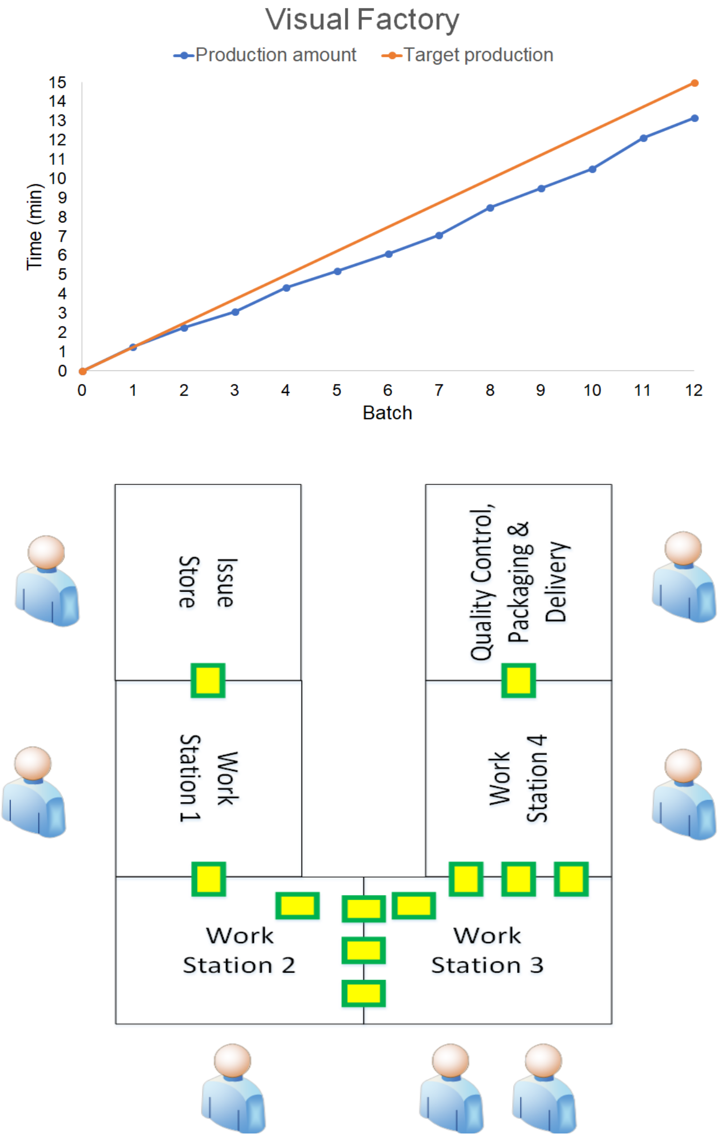

Figure 5: Final layout addressed bottleneck problem and incorporating visual factory in addition to lean manufacturing technique.

Manufacturing theory: the benefits of Pull production systems over the Push system to reduce the Work in Progress (WIP).

Results and Discussion

To evaluate the course design strategy, feedback was collected from the students. It is found that the student experienced a better learning environment with effective implementation of theory into a practical production process. They developed problem-solving skills and understood the importance of teamwork.

Student's perception on different aspects of lean manufacturing theory improved significantly (Figure 6). Students had little/no understanding on the theory of waste reduction, Kanban and focus on constraint to reduce the bottleneck problem. However, their perception improves dramatically after the simulation game. In most of the cases the perception is more than doubled. A potential future study would be how long the students retain this knowledge.

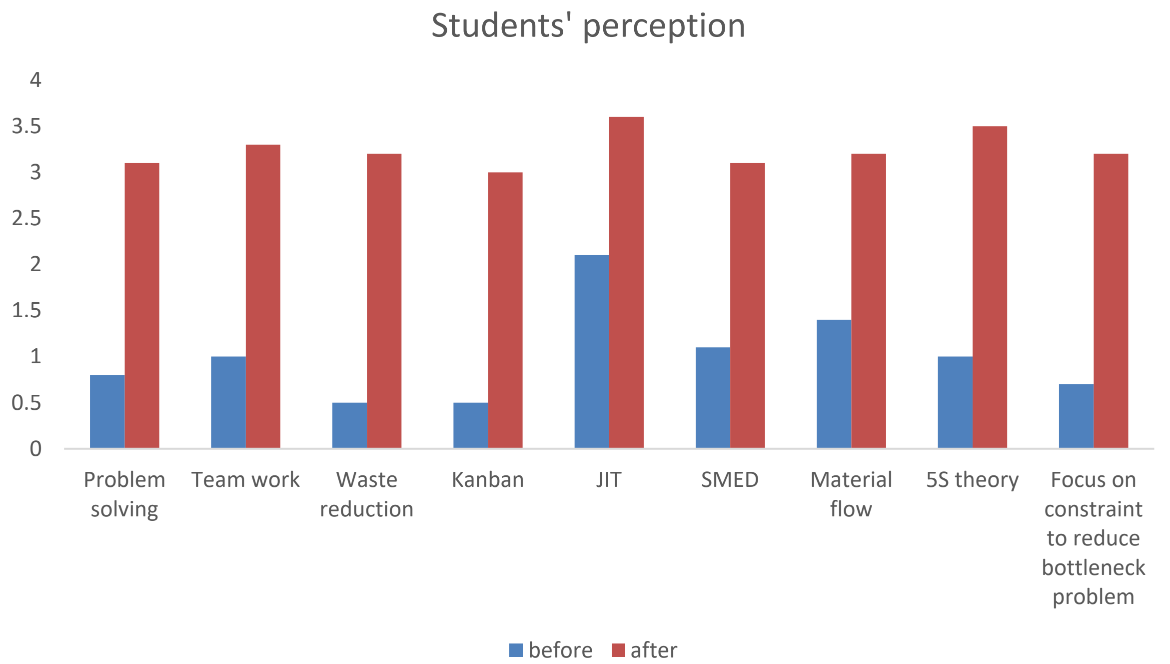

Figure 6: Improvement on students' perception in the different aspect of lean philosophy

Most of the students in Production Engineering course expressed that the learning experience helped them to achieve the desired learning outcome: fundamentals of lean manufacturing theory such as waste elimination, JIT, Push vs Pull production system, autonomation, SMED and continuous improvement.

The students of Production Engineering course highly appreciated the course as below:

- "The theoretical knowledge was reinforced through hands-on activity"
- "Pictorial presentation on how ideas work"
- "Very engaging, learner centred and interactive learning environment"
- "We were able to see the benefit of production system refinement"
- "Having fun while learning."
- "I learn through physical activities (kinaesthetic learner), and this game was excellent."
- "This game helped us to try different ideas, not just conventional talking about it."
- "The learning process was enjoyable because of the hands-on activities."
- "Easier to understand the value of team-work in production environment."

Conclusion

Through, the use of simulation games to mimic a product assembly plant, students gained a deeper understanding of the Lean manufacturing theory: the benefits of Pull production systems over the Push system to reduce the Work in Progress (WIP). They also gained hands-on experience in setup-time reduction through SMED. Students also learned the importance of teamwork in an assembly line of a production facility. This simulation game has the ability to show the benefits of an efficient factory layout. It is a brilliant tool to teach the Lean philosophy. This simulation is suited for situations where the size and cost of some industrial systems cannot be replicated in educational institutions such as large-scale production facilities in a manufacturing plant. Analysis of the student reflections suggests that the simulation game is an effective strategy to introduce concepts of JIT and SMED and to improve classroom engagement through working as a team.

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