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2006-64: TEACHING LEAN MANUFACTURING CONCEPTS USING PHYSICAL SIMULATIONS WITHIN ENGINEERING TECHNOLOGY PROGRAM

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Teaching Lean Manufacturing Concepts using Physical Simulations within Engineering Technology Program

Abstract

Physical Simulations have a proven record as a teaching tool. Concepts that are often hard to grasp are made easy by the use of physical simulation activities. The constructivism learning theory suggests that people learn better by actively participating in the process of learning. Effectiveness of simulation-based learning is well recognized. According to the Encyclopedia of Educational Technology, "Simulation-based learning involves the placement of a student into a realistic scenario or situation. The student is then responsible for any changes that occur as a result of their decisions."

The computer integrated manufacturing course in the mechanical engineering technology program was recently modified to include instruction in Lean manufacturing. A simulation based activity was developed to teach concepts in Lean manufacturing and their implementation within an organization. The simulation activity was developed and pilot tested with graduate students before being implemented within an undergraduate senior elective course. Student evaluations indicate a marked increase in learning and comprehension of Lean manufacturing concepts.

I. Introduction

Major mass and batch producers in the United States have adopted Lean manufacturing philosophy to minimize waste and improve operational efficiency[1]. However, universities are lagging behind in incorporating lean philosophy into their curriculum. A limited number of universities are offering graduate and undergraduate courses in Lean manufacturing. An initial survey of higher education indicated that only ten universities had a course in lean manufacturing and out of these only three were using physical simulation as a tool for teaching Lean.

The educational network within the Lean Aerospace Initiative has taken on the responsibility of developing and disseminating lean curriculum within higher education and bringing the group together to discuss issues related to its implementation. This effort is discussed later in section III.

A previously developed ship repair training program has been incorporated into a senior elective within the MET program to teach students about Lean philosophy and its implementation. This training program utilizes simulation activity to demonstrate the benefits of implementing Lean.

As with any change made within an organization, effective communication and training is a key factor in making a successful transition. A number of organizations have failed in the implementation of Lean Manufacturing[2, 3 & 8]. This is primarily due to lack of sufficient number of trained employees to reach a critical mass for organizational transformation. Training all employees in the principles of Lean is a critical part of Lean implementation process. Educational institutions can help in this process only after incorporating Lean within their curriculum.

II. What is LEAN?

The term Lean was first coined about 15 years ago at Massachusetts Institute of Technology and later published in a book called *Machine That Changed the World,* written by James Womack and his colleagues[4]. The generally accepted definition of Lean in the industrial community is that it is:

"A systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection."

The Lean principles have evolved from the works of Henry Ford and subsequent development of Toyota Production System in Japan. Lean Manufacturing principles improve productivity by eliminating waste from the product's value stream and by making the product flow through the value stream without interruptions[1, 4, and 5]. This system in essence shifts the focus from individual machines and their utilization to the flow of the product through processes[7].

In their book *Lean Thinking*, James Womack and Dan Jones[1] outline five steps for implementing Lean:

1. Specify the *value* desired by the customer.
2. Identify the *value stream* for each product and challenge all waste.
3. Make the product *flow* through the value creating steps.
4. Introduce *pull* between all steps where continuous flow is possible.
5. Manage toward *perfection* by continuously improving the process.

Lean principles were originally applied to manufacturing only but, people quickly discovered their potential in improving other business functions within an organization like finance, human resource and contracting etc. When Lean principles are applied not just to manufacturing but to all business operations both within the organization and across all supply chains, a Lean enterprise is created. A lean enterprise delivers products and services with maximum customer satisfaction while utilizing minimum resources.

III. Lean Education Academic Network (LEAN)

A new educational alliance, the Lean Education Academic Network (LEAN) has been working to develop and disseminate Lean educational curriculum within higher education. This is an LAI organization where EdNet members expect to find much synergy and stimulating collaborative opportunities. Participants here learn about lean engineering, incorporating lean into on-campus curriculum and LAI research projects. The LAI Educational Network (EdNet) currently is a group of 30 universities and colleges working together with LAI industry and government members to develop and deploy curriculum based on lean and Six Sigma research and practical knowledge. MIT, Old Dominion University and USC are few of the universities. In 2003, the LAI EdNet was formed among institutions of higher education with two specific objectives: To support continuous learning throughout the US aerospace enterprise by sharing knowledge and curriculum and secondly to develop and deploy curriculum that teaches lean principles at key universities, businesses and military institutions.

Various universities in recent times have proposed the establishment of LAI EdNet centers to allow greater deployment of Lean. The LAI Lean Academy has started one-week course that provides a hands-on introduction to lean fundamentals. It is targeted towards undergraduate students, and is taught at the point of use during an internship/co-op. One of the key approaches of the Lean Academy is to provide industry personnel for teaching these courses. The LAI Lean Academy also serves as a platform to advance the capability of university faculty to teach lean, develop lean curriculum, stimulate the diffusion of lean principles into on-campus coursework, and build partnerships between industry and academia. At University of Alabama, Huntsville a special interest group is formed to discuss the intellectual convergence of lean principles and systems engineering and how lean can be integrated best into its graduate/undergraduate level courses.

IV. Physical Simulation as a Teaching Tool

Physical simulations have a proven record as a teaching tool. Concepts often hard to grasp are made easy by the use of simulation exercises. The constructivism learning theory suggests that people learn better by actively participating in the process of learning. In order to involve students into the participatory learning process, the interaction among students, and between students and the instructor in a classroom setting becomes very critical. Effectiveness of simulation-based learning is well recognized. Edgar Dale's cone of learning as shown in Figure-1 supports the benefits of simulation based learning. According to the Encyclopedia of Educational Technology[6], "Simulation-based learning involves the placement of a student into a realistic scenario or situation. The student is then responsible for any changes that occur as a result of their decisions."

Educators have been designing, using, evaluating and writing about simulations for more than 45 years. However there are no generally accepted definitions of an education simulation or its many variations. Education simulations are sequential decision-making classroom events in which students fulfill assigned roles to manage discipline-specific tasks within an environment that models reality according to guidelines provided by the instructor. Education simulations typically place students in true-to-life roles, and although the simulation activities are "real world," modifications occur for learning purposes[11].

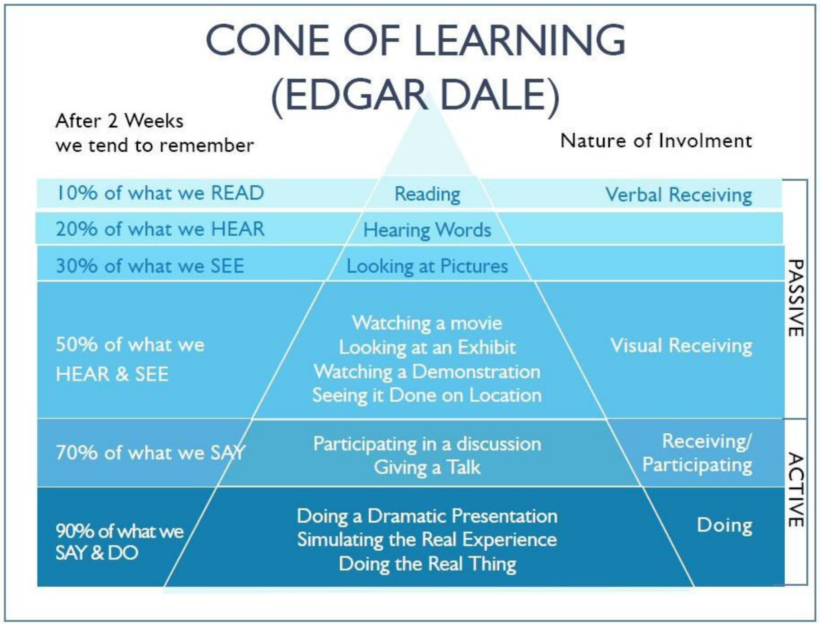

Figure-1, Cone of Learning by Edgar Dale

Another important use of simulations in education is to facilitate efforts at what has become known as "bridging the gap" between academics of profession and practice of that profession. Simulations are ideal for connecting factual knowledge, principles, and skills to their application within a profession. Simulations help students with an opportunity for decision making, and for evaluating the consequences of their decisions that no textbook or laboratory can.[12].

Simulations weave substance-specific information into real life problems in meaningful ways that students can understand. During simulations, students typically acquire broad discipline-specific knowledge that they are able to later transfer into a professional setting. Simulations also teach much more, including the process involved in the discipline, the organization involved, and the interactions with other discipline, people, and organizations.

The entire structure of simulation is built around the concept of students participating in variety of roles within an environment, designed around the learning objectives of the course. During simulation, learning happens because the students are active and not passive in the process. They are able to experiment with various options and interact with fellow students. Increasing student's knowledge is an important goal of all education. Simulations are particularly adept at helping students acquire usable knowledge that is knowledge that can be transferred and applied to other situations. Simulations encourage purposeful use of knowledge to achieve clearly defined goals.

V. Incorporating Lean within MET Curriculum

Lean material has been incorporated into the MET curriculum via a senior elective titled Computer Integrated Manufacturing (MET-445). Approximately 20% of course deals with Lean manufacturing. Lean coverage starts with lecture on Lean principles followed by the training program in ship repair and associated simulation activity. The goal of this course is to provide the students with competency-based, hands-on learning that supports a systems approach about Lean philosophy and its implementation. Prerequisites for the course include general knowledge about manufacturing systems and sophomore level course in materials processes and manufacturing. Student responses have been collected and evaluated via an attitudinal survey. Student comments indicate positive response towards the program content and simulation activity.

VI. Attitudinal Survey to Assess Impact of Lean Training

The challenge of Lean implementation is in changing how people feel about their day-to-day manufacturing job. Application of Lean tools is relatively simple compared to changing the work culture and attitudes. Thus, it is important to assess the change in the attitude of people.

An attitudinal survey was created to assess the impact of Lean training on the thinking of students. The attitudinal survey assesses how a student's thinking about Lean Manufacturing has changed during the training on a scale of 1-5. A score is generated from the survey from pre and post testing. The difference in the score represents the change in the attitude of students. Thus, a larger difference represents higher impact of training program on student's thinking. A copy of the survey is attached in the Appendix.

VII. Delivery Method

The course is instructor-led classroom training combined with in-class simulation exercises designed to invite class participation. This approach aids in the individualized instruction given to the participant. Instructional methods include facilitated discussion, hands-on simulation of production, and on-the-job practical applications. PowerPoint presentations are used to deliver the course, supplemented by a series of videotapes from Society of Manufacturing Engineers and Productivity Inc. Students are encouraged to participate in the Lean implementation projects. In addition a semester project on production simulation using ProModel software is also required.

VIII. Ship Repair Simulation Exercise

This simulation exercise incorporates repair of two ships of different sizes. One of the ships is shown in Figure 2. During the simulation, students track performance metrics like lead-time, cycle time, rework and distance traveled by material handler while implementing various tools of Lean in three phases. This exercise takes into account logistical issues such as inspection reports, master repair schedules, emergent repairs, in addition to planned repair activities. This simulation exercise simulates repair activities such as painting, blasting, engine overhaul, shaft straightening, pipe replacement, and deck plate replacements.

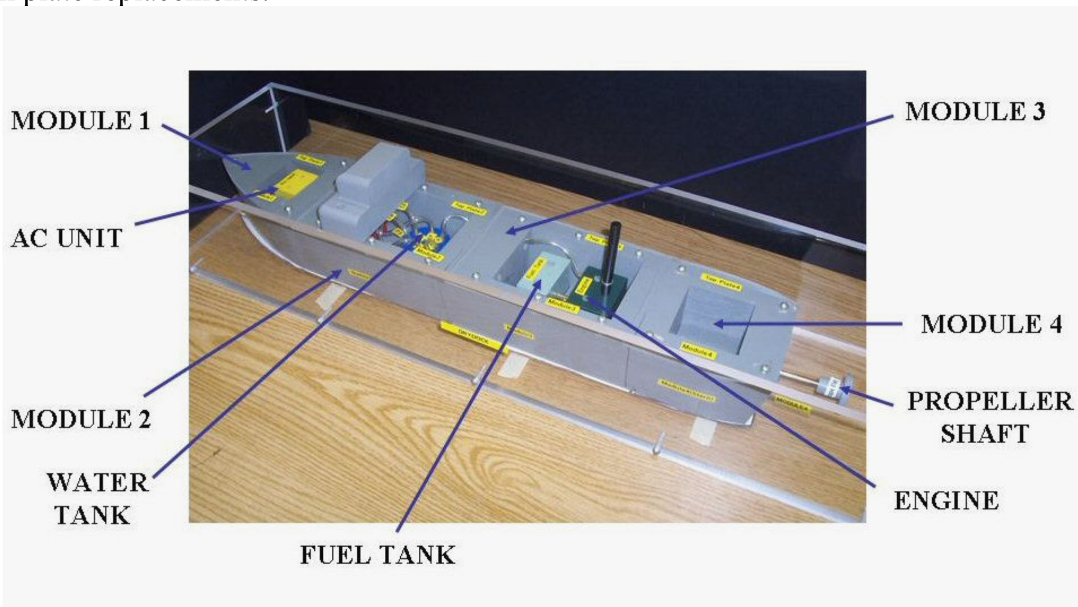

Figure-2, Ship Repair Simulation Model

Fourteen to twenty people can participate in this simulation. During simulation participants are assigned to seven different departments: planning, hull, machinery, production shop, warehouse, waterfront services, and inspection.

The simulation exercise starts with the traditional manufacturing model involving push system and functional layout. During this phase, lack of communication between different departments increases process lead-time. During the second phase, Lean concepts like 5-S, standardized work, point of use storage, and communication are incorporated. Finally, during the third phase concepts like cradle to grave approach, line balancing, and empowered teams are implemented. These three phases of simulation activity are shown in Figure 3. At the end of each phase of simulation, data such as cycle time of different repair jobs, lead-time, rework cost and distance traveled by waterfront services is collected. Using this data, impact of Lean implementation is assessed[14].

The physical models of ships were fabricated at NGNN pattern shop. The components are fabricated from wood and include ship parts such as engine, A.C. unit, water tank, fuel tank, heat exchanger, smoke stack, propeller, propeller shaft, captain's cabin and crew cabin. The dry dock and deck plates are fabricated from acrylic. The components are assembled together using dowel pins for positioning and fastened with brass screws. The components are designed to withstand repeated assembly and disassembly. Some of these components are shown in Figure 2.

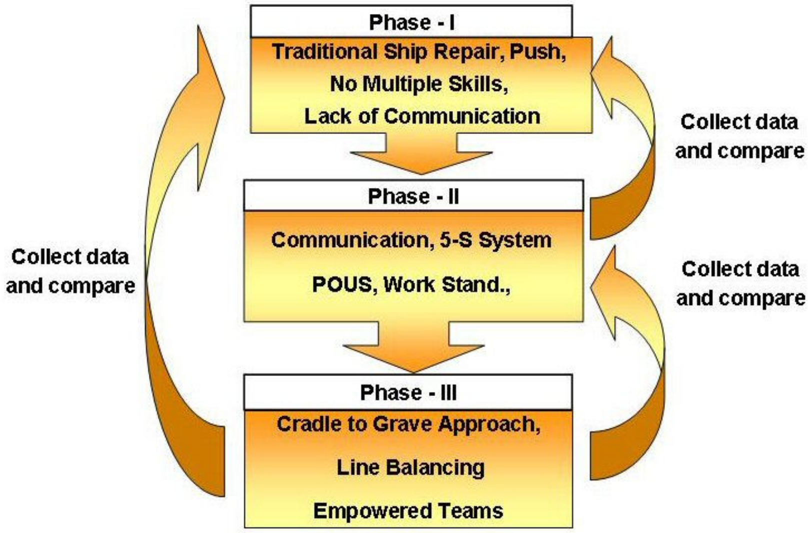

Figure-3, Simulation Phases

IX. Implementation of the Simulation Activity

As mentioned above, the Lean modules were implemented in a course titled Computer Integrated Manufacturing (MET-445). After being introduced to theoretical knowledge about Lean Manufacturing, the students are asked to simulate the process of ship repair. The simulation begins with the class playing the roles within a fictitious company named ABC Inc. Job responsibilities are discussed and student volunteers are assigned to various positions needed to manufacture the product. The goal for the company is to finish the repair job on time (within 13 minutes).

ABC Inc. is a general purpose marine repair company that performs work like blasting, painting, hull repair and engine overhaul. During the first phase of simulation, traditional repair and maintenance techniques are used. The employees are given strict rules to follow with very limited authority. Data is collected after the first ship repair order is complete. Average cycle time, number of employees, number of workstations, lead-time, distance traveled, and rework cost are the performance metrics that are analyzed. The numbers are input into an Excel spreadsheet. In most cases phase-1 takes 30 minutes to finish the repair job.

It is at this point that the students are reminded of some of the Lean concept taught earlier in the class. They begin to use several Lean building blocks to improve the process. Ideas such as point of use storage, 5S, multi-functional workers, and standardization surface quickly in group discussion. Systematically, the students begin to implement Lean ideas, and thus improving the process and finishing the repair job in less time. The second phase is completed and data is collected. This phase usually takes 20 minutes to complete the repair job. The students are usually excited to see the turnaround that they are responsible for; however they are reminded that the company cannot survive by simply having each shift break even. Figure 4 shows the simulation activity at the Dry Dock and at the Production Shop.

Figure-4, Simulation Activity at Dry dock and Production Shop

As the students return to the table to brainstorm ideas of how they might improve the process even greater, a new set of Lean tools is introduced in the classroom. The students then set-up and run the process a third time implementing as many of the Lean concepts as possible. The data after one shift is collected and the bottom line is computed. Typically, repair job is completed on time. At this point the students are quite excited and are very proud of their accomplishments.

X. Results

The Lean training and simulation activity has been well received by students. Comments at the end of the course reveal that student enjoy learning the Lean concepts with the simulation exercise. Figure 5 shows the histogram of student responses from the pre and post training evaluations. The x axis represents the scale 1-5 on which respondents evaluated questions on the attitudinal survey, 1 being strongly agree and 5 being strongly disagree. The student responses were fitted to a polynomial and the value of mean is indicated by a dashed line. Figure 5 clearly indicates that the post training response curve is skewed to the right. Before the simulation training, mean of student responses was 3.31 and after the simulation activity this mean moved up to 3.73. This indicates that the class room training utilizing physical simulations had an impact on the learning and retention of the participants.

XI. Conclusions

This study shows that, learning of Lean concepts is made easier by incorporating physical simulations within the course material. Student learning is also enhanced by including examples of actual Lean implementation in various industries. Hands-on simulation exercises provide understanding of the concepts and first hand verification of the advantages of Lean.

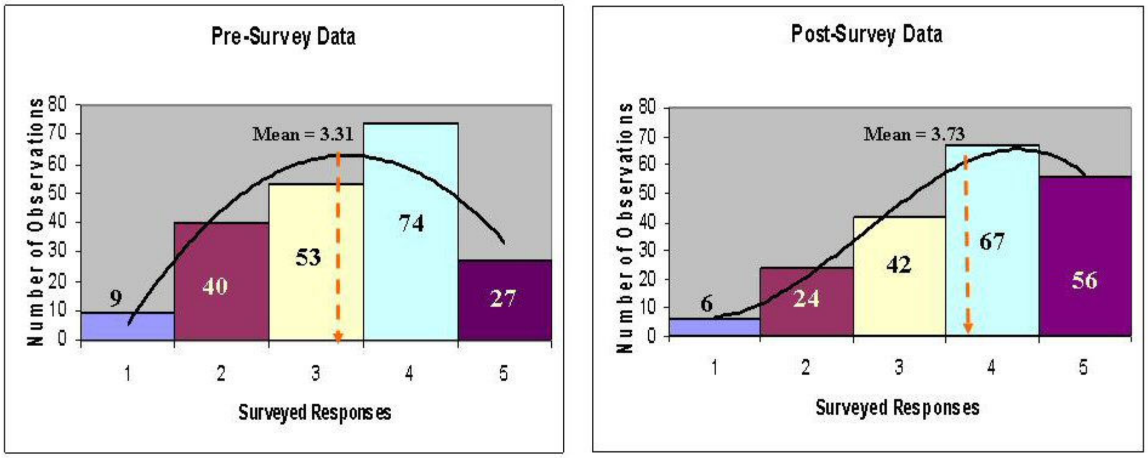

Figure-5, Plot of Student Responses

Incorporation of Lean principles and ship repair simulation into a senior elective creates a course that is both engaging and educational for students. The primary goal for making this change is to ensure that students are familiar with this powerful philosophy before stepping out into real world. Comparison between pre and post attitudinal survey results indicate statistically significant improvement in students understanding of Lean concepts and tools.

Acknowledgements

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