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Teaching Lean with an Interdisciplinary Problem-solving Learning Approach*

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Faculty from Oakland University's engineering, business and education schools working with Oakland University's Pawley Learning Institute, are teaching graduate students lean principles and applications in a unique venue. An interdisciplinary elective course entitled Lean Principles and Application educates students enrolled in engineering, business and human resource development degree programs about lean from different perspectives before they enter the workforce. By providing students with the knowledge and skills to implement lean principles to solve real world problems, these future employees are prepared to add immediate value to their companies. In order to achieve this goal, a problem-solving learning component is implemented involving a semester long project where student teams conduct a lean analysis of a real-world manufacturing system or service system.

Keywords: Lean manufacturing; industry partnership; interdisciplinary

INTRODUCTION

LEAN HAS BEEN DESCRIBED as a system that uses fewer resources to design and produce products economically and with better quality [1]. The principles and concepts of lean manufacturing (also know as the Toyota Production System), such as the total elimination of waste and continuous improvement (kaizen), are becoming increasingly adopted by businesses in an effort to better compete in today's global market [2], [3]. In one of the most competitive industrial markets, the North American automotive industry [4], the effective application of lean manufacturing techniques is helping to improve performance [5]. Because of this competitive environment, there is a great need for employees who are able to participate in as well as lead the necessary changes in existing business cultures, operating systems and operational practices in order to achieve world class status [6], [7], [8] and [9]. Employees with lean skills are in demand not only in manufacturing industries, but also in the service industries [10].

Typically, organizations that utilize lean practices as a function of their continuous improvement philosophy invest numerous resources including time and money to educate employees. But there is a cost associated with the ongoing training of employees, in addition to an impact on the business as a result of removing employees from their normal work duties during training [11], [12]. Individual employees trained in lean are often unable to implement the principles and tools learned once they are back on the job because lean practices are not embedded in the knowledge base of the company's workforce [11].

In 2002, faculty from Oakland University's School of Engineering and Computer Science, School of Education and Human Services, and School of Business Administration met with personnel from Oakland's Pawley Learning Institute to begin developing an interdisciplinary course on lean. These faculty members recognized, as have others, [8], [9] and [13], that an excellent way to teach lean is in an interdisciplinary environment. The mission of the Pawley Learning Institute is 'to provide instruction, research and further develop the principles and practices of lean organizational improvement for business, education and public service'.

This course is designed for students enrolled in Oakland University's Engineering M.S. programs (electrical and computer, engineering management, industrial and systems (formerly systems), and mechanical), Masters of Business Administration (MBA) program and Masters in Training and Development (MTD) program. The focus of the course is on the application of lean concepts across the entire enterprise, not exclusively in the manufacturing environment. The course is entitled *Lean Principles and Application* and is cross-listed in all three schools.

The course debuted during the 2003–04 academic year. It is team-taught using faculty from each of the three schools and incorporates presentations by lean practitioners from industry.

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An important component of the course is a semester-long, problem-based team project that focuses on problem solving.

Problem solving is a purposeful activity directed at achieving a goal through the introduction of a nontrivial problem that has several possible solutions, [14]. In order to function in a lean workplace environment, students need to learn how to solve complex problems that cross disciplinary boundaries, [8], [9], [15]. Hence, the faculty team decided that the focal point of the course would be a problem solving project.

Problem-solving activities have been successfully used to provide an appropriate structure for organizing and sequencing lessons [16], [17]. Some of the advantages of problem- solving activities include having the students apply the concepts presented in class in an immediate fashion and providing alternative means of feedback to the instructors regarding student comprehension of course content.

COURSE DEVELOPMENT

Given the broad nature of the topic, the challenge of creating a lean course included having to deal with the following issues.

- The existing body of faculty knowledge concerning lean.
- The expected level of learning and outcomes from students enrolled from three different schools.
- Available class time.
- The breadth and depth of lean content and the resulting class assignments.
- The consistency and continuity of instruction, class format and course content between faculties from three schools.
- The incorporation of real-world knowledge, application and learning.

One of the expectations of the course is to prepare students with knowledge and skills related to the understanding of lean theory, rules/principles, concepts, tools and supporting systems based upon interdisciplinary perspectives and instruction. Participating faculty and staff from the Pawley Learning Institute met numerous times to develop the course's learning outcomes. In order to satisfactorily complete the course, students are expected to demonstrate competency concerning their understanding of the following learning outcomes:

- Define terminology associated with lean and lean manufacturing.
- Discuss the theoretical and historical framework that leads to lean concepts and principles.
- Observe and analyze work as activities, connections and flows.
- Identify the symptoms of waste in a work environment and in a simulated activity.
- Differentiate between processes and activities that are value added and non-value added.
- Participate in a team continually trying to improve.
- Apply the appropriate tools to eliminate the root causes of waste.
- Apply the appropriate rules/principles, concepts, tools and supporting systems of lean in simulated activities.
- Define and discuss the necessary interrelationships by which people, processes, tools and systems operate at peak effectiveness within a lean environment.

The class meets once a week for approximately 3.5 hours and is held over a 15 week semester that culminates with a final class dedicated to team project presentations. The selection of course topics is determined through an iterative process among participating faculty with input from the Advisory Board members and staff of the Pawley Learning Institute. Note the Advisory Board of the Pawley Learning Institute includes executives and lean practitioners from several companies with established lean programs.

The course topics for the 2006 fall semester are shown in Table 1. This list of topics, as well as all other aspects of the course, has evolved since its initial offering in 2003 through a continuous improvement process applied by the participating faculty.

PROBLEM-SOLVING COURSE PROJECT

The main focus of the lean course is a semester-long, team-based project involving a partnership

Table 1. Lean course topics

Week	Topic
1	Introduction to Course; Review Syllabus; Introduction to Lean
2	Process Design and Waste Reduction Strategies; Introduction to Project Assignment
3	The Role of Teams: Teams are Chosen; Project Assignment Problem Statements
4	Overview of Production Systems; Value Stream Mapping: The Current State; Current State Simulation
5	Value Stream Mapping: The Future State & Lean Tools
6	Value Stream Mapping: The Role of People in Lean
7	Value Stream Mapping: Completing the Process; Future State Simulation
8	The Role of Culture in Lean; The Role of Leadership in Lean
9	Project: Student Presentations of Current State VSM; After Action Review of Presentations
10	Lean Accounting
11	Supply Chain Scheduling and Its Impact on Waste
12	Supply Chain Variance Reduction; Supply Chain Simulation
13	Project Team Working Session
14	Panel Discussion: The Role of The Leader
15	Class Project: Final Presentations

with a local company. The creation of this lean course provided an ideal opportunity to design a problem-solving activity as the foundation on which to teach the content. In a study of baccalaureate physics students employed in business and government, more than 60 per cent responded that problem solving, interpersonal skills, technical writing and management skills were more useful in the workplace than physics skills [15].

The selection of a partner company was crucial to a successful problem solving project. The faculty team constructed the following criteria for selecting a company partner for the project.

1) A receptive management and workforce that will allow student teams access to shop floor processes, material flow, information systems and data in addition to allowing minor disruptions to normal work activities.
2) Existing opportunities to apply lean concepts and practices based upon the current state of the company's lean transformation, work activities and processes.
3) A desire to participate in a win/win relationship with an understanding that the students will learn more about lean through real-world application and the company will benefit from the close examination of its current state processes as well as from the ideas and recommendations for improvement generated by the student teams.

In addition to the proper match with a company and the class, the structure of the project was extensively analyzed and developed. Student team formation, problem statements, how the teams interface with the company representatives and employees, faculty mentoring and involvement with each team were determined. At the end of each semester, an overall course kaizen activity with specific focus on the team project activity was done by the participating faculty and improvements for the next semester were made. The following is a narrative on the evolution of the problem-solving team projects during the first four offerings of the course, including lessons learned and improvements made with each offering.

Course project—first year

After the course development team visited several companies, NuStep Inc. of Ann Arbor, Michigan was selected as the host company for the project. NuStep is a small, privately-owned company that manufactures a rehabilitation product called the TRS 4000 Recumbent Cross Trainer used in therapy/fitness centers, hospitals and cardiac clinics.

Cross-discipline teams comprising six students each were established early in the course by a random drawing of names from three pools of students grouped together based upon the school they were attending. Every team contained two students from each school. The objective was to form a team with diverse skills, education and backgrounds, not unlike teams of employees that typically work on continual improvement activities.

The four teams were each assigned a team-specific problem statement as well as two common class-wide problem statements. The problem statements were developed incorporating research on effective problem-solving statements [16], and with the input and concurrence of NuStep's management personnel.

The four team-specific problem statements were:

1) Develop a plan to implement systems thinking throughout the manufacturing system. Determine sources of variation and implement statistical process control wherever it is applicable in the manufacturing system.
2) Develop a plan to minimize variation as well as to predict dimensional accuracy and throughput of robotically welded components.
3) Design and implement a kanban controlled reorder system for material flow between the fabrication and assembly departments.
4) Develop a plan to implement lean systems throughout the manufacturing system.

The common problem statements given to each team were:

1) Estimate the current capacity (throughput and quality) of the manufacturing system and make recommendations to improve throughput.
2) Develop a plan to effectively train the workforce in lean principles and create a culture centered on process thinking and continuous improvement.

A nominal amount of basic information related to NuStep's history, product, manufacturing processes and business processes was provided to each team. The teams were then tasked with data collection and analysis in order to develop their solutions. Team coaching and mentoring was provided by faculty members.

The class made two all day Saturday site visits at NuStep's plant. Some team members also made a third visit to collect additional data. At the end of the semester, formal team presentations were made to the other student teams, faculty and NuStep personnel as well as representatives from the Pawley Learning Institute and lean practitioners from local industry.

Evaluation of the teams' project report and presentation accounted for 40 percent of each student's grade and was based upon the following criteria:

- Quality of the current value stream map generated by the team.
- Value analysis as well as wastes identified, quantified and documented by the team.
- Lean principles incorporated in the team's solution.
- Quality of the team's solution as measured by potential impact on throughput and cost.

- Quality of team's presentation and interaction with the audience.

Course faculty and NuStep management were pleased with the solutions presented by the student teams. Several sources of waste in NuStep's manufacturing system were identified and suggestions for reducing them were presented. Due to the limited constraints contained in the problem statements, many of the teams' solutions were unrealistic for NuStep to implement because they tended to require large capital outlays as well as significant manufacturing system downtime.

One method to assess the course was student evaluations completed at the end of the semester. Four of the survey questions in this evaluation concerned the problem-solving project. These questions are listed below followed by a representative selection of student responses.

1) List ways in which the project was useful.
   'Experience with real world project.' 'Networking, interacting in a group that is cross functional.' 'Identifying the realities of manufacturing in the local environment.' 'The project has simulated how teams work in the corporate world. My fellow team members introduced me to new ideas and offered new perspectives on issues.' 'I am accustomed to working with HRD students who have all been taught the same material as me, so they think the same way I do. It was interesting to work with people who don't understand the relevance importance of HR and training.' 'I had to learn to introduce ideas in a different way, rather than use HR vocabulary.' 'I believe that this experience has taught me how to better communicate with others, learn to accept criticism and learn from others.'
2) List ways to improve the project.
   'Students learn current state value stream mapping and seven kinds of waste before going to NuStep.' 'Our team wasted a lot of time in the beginning because we thought it was necessary for all members to work on all tasks as a team. We worked more cohesively as a group once we concentrated solely on our individual areas of expertise and presented our individual ideas to the group.' 'More guidance and direction.' 'A few helpful hints as to what the team should do and look for suggesting engineer and business students focus on processes while HR focus on people and culture.' 'The second visit was better because we were focused but it probably could have been avoided if we knew what to focus on for the first visit.'
3) What class would you have liked to have before visiting NuStep's plant?
   'A class on current state mapping.' 'MPS and MRP overview.' 'Information from each college from a macroscopic level.' 'Seven wastes and some examples of lean transformations from literature.'
4) Additional comments concerning the problem-solving project.
   'Break the overall problems that NuStep faces into smaller steps.' 'Allow the groups to select from the problem list.' 'More time with the Lean systems and tools.' 'Help us learn and recall seven wastes and results of each.' 'Discussion on how we should interact with the managers and employees.'

Overall student responses were generally favorable but the problem-solving project required detailed review and revision. The following describes the kaizen and details project improvements made before implementation in year two.

Course project— second year

Following the lean principle of continuous improvement, a kaizen event [1] for the course was conducted by the faculty team. The kaizen team reviewed feedback from NuStep personnel and guest lecturers (primarily from industry) along with the student evaluations.

As a result of this kaizen, the course problem-solving project was modified as follows:

- An increased focus on lean concepts was incorporated into the project.
- The seven wastes and examples of lean transformations were defined and presented before project start.
- Each team received the same problem statement, but had to develop a solution for a different area of NuStep's manufacturing facility.
- Additional corporate information was presented to each team, including economic constraints in the problem statement allowing for more effective and realistic solution recommendations.

The class was once again divided into four teams, but only three of the teams were interdisciplinary in nature. The three interdisciplinary teams contained all the students from each of the three programs. Since only three Masters in Training and Development (MTD) students enrolled for the course, these students were also members of a fourth MTD team. This allowed the MTD students to work as a team to address human resource problems identified by NuStep and the interdisciplinary teams.

NuStep's manufacturing facility was divided into three separate areas. Each interdisciplinary team was assigned an area. As in the first project, a problem statement was developed with the assistance of NuStep personnel. The problem statement for each interdisciplinary team was as follows.

1) In your assigned area, identify, quantify, document any non-value added activities and/or related resources, and develop a plan and the associated tasks to reduce/eliminate them. Hint: To the best of your ability, start by utilizing the value stream mapping technique.
2) Consider all of the inputs, conversion activities, resources and outputs for your area. Identify and document the cost savings or any other advantages of clearly connecting to your sup-

plier and customer, and operating to the cellular concept vs. the current state, if any.
3) Create a lean operating system (i.e. optimal manpower, materials, operator and machine times, standardized work, instructions/procedures, training methods and a visual environment) that will enhance flow based on actual usage or the rate of consumption of the customer.
4) Establish the pace of production for your area in accordance with the operating system and based upon the concept of pull (i.e. producing no more than what the downstream customer uses or consumes). Identify and document the triggers, signals, quantities and system rules that will support this objective. All matters of implementation and sustainability should be considered and taken into account.
5) If capital expenditure is required to address the statements above, calculate and document the Return on Investment (ROI) and Net Present Value (NPV) financial evaluations. This must be favorable for any significant outlay of capital.

The course faculty and NuStep management personnel believed the performance of the student teams improved over the first project. The solutions were more focused on continuous improvement, rather than recommending major redesigns of the manufacturing system as was common in the year one projects.

Student evaluations were transferred to the School of Engineering and Computer Science online course evaluation system during the second offering of the course. The students' rating of the problem solving project was a 4.0 out of 5.0 (scale: 5 = excellent, 4 = good, 3 = average, 2 = poor, 1=unsatisfactory). The students' 'overall rating of this course as a learning experience' was 4.1. Representative student comments concerning the project are as follows:

> 'Excellent. Bring the Real World in.' 'Course needs to be designed around visits to plant. Class time should be used each week to discuss the things going on at the plant. Before the visit should relate topics covered in class with processes in the plant.' 'There needs to be much more structure before it begins. Deliverables must be clearly defined.' 'Do more site visits.' 'This was a great initiation to lean manufacturing. My expectations of what I was going to get out of it were overachieved.' 'The opportunity to meet and work with the people at NuStep was the best part of this class. They were the motivation to keep going and to try my best to evaluate where they are and make positive suggestions to help them reach their goals.'

Student responses in year two indicated approval for the problems selected and the structure of the overall project, but the site location needed to change. A location closer to the university would allow students easier access to the employees and the site, hence, increasing the amount of interface they could have with the company. The following describes the kaizen and details project improvements made before implementation in year three.

Course project—year three

After the kaizen of the course's second year, it was decided to again use problem statements similar to those of the second project. However, a new industrial partner was selected for the third project, Foamade Industries in Auburn Hills, Michigan. Foamade Industries is involved in the development and fabrication of flexible urethane products.

There were three reasons for selecting the new industrial partner:

1) to ensure that solutions from the second project were not used again;
2) to better integrate the project assignment with the lectures;
3) to select a location closer to Oakland University.

The new partner's manufacturing facility is three miles from Oakland University. This allowed for several of the lectures to be held at Foamade's manufacturing facility. Hence, the students could spend time in the manufacturing facility before and after class.

At the end of this semester an informal assessment was held for the course. The instructors met groups of students to discuss the course. Student comments and concerns were similar to those from the previous course with the exception that the students appreciated the company hosting some of the course lectures on-site allowing students to access employees and the manufacturing floor before and after the designated class time.

Course project—year four

This year's plan for the class project was similar to year three working with Foamade Industries. However, a few weeks before the beginning of the semester the local company had to withdraw from the class project. The faculty team had been discussing the possibility of conducting a project in the service sector rather than in manufacturing. Hence, the project was changed to focus on Oakland University's student advising systems.

The goal of the project was to 'align and balance the *voice-of-the-customer* requirements with Oakland University's student advising systems'. The project was conducted in two phases. In phase 1, teams determined the current state of selected advising systems at Oakland University. Four teams were formed with one team being assigned to each of the following advising systems:

- undecided majors
- business majors
- College of Arts and Science majors
- Engineering majors

During phase 2 of the project, the teams developed a proposal for the future state of their advising system.

In addition, the presentation format was modified. Rather than presenting the entire results from the project at the end of the semester, a mid-semester presentation was implemented with the teams reporting their analysis of the current state of the system. This ensured that the teams were on the correct path to develop their proposals for the system's future state which were presented at the end of the semester.

Student evaluations were once again collected. The students' rating of the project was 3.7 on a 5.0 scale. Their 'overall rating of this course as a learning experience' was 4.4. Representative student comments concerning the project are as follows:

> 'Good course to take, would have liked to see us go through the entire nine-step process with a smaller project as opposed to a project that made assessing the current state such a difficult task.' 'The course was excellent with the exception of the project. The reason I had selected this class was not for the general lean discussions. It was because I was looking forward to the opportunity of going into a manufacturing facility, and applying lean concepts in a hands-on way.' 'Learning lean in an office environment is important, but I believe it is also more difficult.' 'It would have been much better if the project was on a manufacturing process.' 'I thought the project this semester had a certain incompleteness to it despite the project holding great promise as a concept.' 'I liked the idea that we were applying lean to a non-manufacturing example." 'Trying to learn the advising process and the lean principles at the same time was too much.' 'It would have been nice to have a group project that analyzed a more traditional manufacturing/production system.'

The faculty team reviewed this feedback with great scrutiny because it was the first non- manufacturing problem solving project. Students were required to learn the student advising process while also learning and then applying lean principles to a complex problem. Although feedback indicated overall value, several changes were identified for the next course offering.

DISCUSSION

Designing and implementing a graduate course using an interdisciplinary team approach with an evolving topic such a lean is in and of itself an ambitious effort. While there are exceptions [8] and [9], university structures in the US do not easily lend themselves to a course taught by three faculty members across three schools. Administrative issues including faculty reimbursement, course listing and overall instructor record need to be addressed. For many, these barriers are sufficient to halt any effort in this direction. Interestingly, these were not the issues that needed our focus. In part because of the dedication of each faculty member to teaching lean principles in their area, and the understanding of the opportunity to the students, the administrative issues required little of our attention. This allowed the faculty kaizen efforts to focus on the problem-solving project.

The students' feedback and suggestions from the assessment process were taken under advisement and used to improve the course. The following are specific improvements implemented into the course project:

1) Students are introduced to the seven kinds of waste, the initial steps of process mapping, and team behaviors and expectations before the initial site visit.
   The structure of the course content now provides students with an introduction to lean, process design and waste reduction strategies, the roles of teams in lean, and the problem statements the teams will be working on the remainder of the semester (see Table 1) before the first company site visit. This supplied students with the tools to focus specifically on the project while minimizing frustration. In addition, realizing that students bring their own 'language' from the programs they reside in, a common communication is essential to team success [18]. The formation of the teams and team communication activities introduce the students to the common language they will use for the remainder of the semester.
2) Additional guidance, direction and mentoring given to the teams from the faculty.
   The ability of a facilitator during a small group activity is the major determinant of the quality and the success of any educational method aimed at developing students' problem-solving abilities while they learn [19]. Although each faculty member is assigned specific weeks and topics for class lectures, all of the faculty members work with the student teams on site during the company visits. The faculty guides the learning through a series of questions probing students' knowledge while refraining from giving their opinion unless the groups are veering too far off track.
3) The structure and content of problem statements is clear.
   Characteristics of good problem statements may vary somewhat according to the discipline. Students from three disciplines present a challenge in structuring the problem statements. There are general characteristics of good problem statements that are incorporated into them. These include creating problems that engage the students' interest and motivate them to seek a deeper understanding of the concepts introduced. Problems that force students to make decisions while being complex enough that all members of the student group must participate in order for the team to effectively work toward a solution [15]. We begin this process by choosing a central concept to be taught in the class (i.e. process mapping), choosing the real-world context (the company), and finally introducing the problem to the students and providing them with the resources they need to solve it.
4) The course is designed around site visits. Class time is used each week to discuss the project.
   Choosing a company located close to campus

with the facilities to hold classes on site solved this challenge and proved to be an essential element in the project success. Students often have questions, ideas, or solutions while learning course content that relates to the problem-solving project. Being onsite allows them the opportunity to test new ideas and ask questions as they unfold in class.

5) The project will focus on a manufacturing problem.
Although applying lean principles is applicable in non-manufacturing settings, after working in a manufacturing and non-manufacturing setting with this project, the faculty decided a manufacturing setting is more appropriate given the constraints of this class. Fifteen weeks is a short cycle time to introduce and apply concepts in an interdisciplinary approach; the given structure of a manufacturing environment provides the framework to allow students greater opportunity to solve semi-structured problems and implement lean principles. It is possible, however, to use non-manufacturing processes (such as HR processes) in the manufacturing company while simultaneously working on the larger problem statements.

CONCLUSION

The basic goals of higher education are wide and varying. The Oakland University Pawley Learning Institute's expressed goal is to educate students in such a way that they are better prepared to succeed in the workplace by offering them an interdisciplinary educational program that is directly related to and addresses today's critical manufacturing and business issues. Through the design and implementation of this interdisciplinary lean course, faculty from the schools of Engineering and Computer Science, Business Administration, Education and Human Services have created an opportunity for students to learn and apply lean in an innovative manner.

The cornerstone of this course is the problem-solving group project. Continuous improvement of the project has resulted in the evolution of a sound problem-solving opportunity for the students. The faculty team will continue to collect data on student reactions to improve and create a challenging learning experience as well as to develop students who are better communicators, possess the ability to work in groups, are critical thinkers and creative problem solvers.

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