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Problem-Based Learning for a Lean Six Sigma Course

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Abstract
A Lean Six Sigma and Supply Chain Management, MBA-level course, averaged 15 students per semester. A persistent issue was that, even with in-class exercises to develop theoretical understanding, students were often unable to analogize to real-world situations. By introducing problem-based learning (PBL) the instructor broadened the teaching methods by introducing a consulting project for a local food bank. The food bankâ s warehouse had been open for six months but had already become unwieldy to manage. Course readings, lectures, and in-class Lego assembly exercises provided the scaffolding for building studentsâ mental frameworks. Then their frameworks were tested and reinforced through the consulting engagement enabling them to learn more than each alone could provide. In the course of the consulting commitment, students engaged in Gemba walks, performed several types of analyses (e.g., state, process, root cause, value chain, etc.), and, via PBL, identified problems and developed solutions to meet organizational goals, while applying theories and skills taught in the course.

Keywords: Lean six sigma, supply chain management, problem based learning, scaffolding, consulting project

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PROBLEM-BASED LEARNING FOR A LEAN SIX SIGMA COURSE

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ABSTRACT

A Lean Six Sigma and Supply Chain Management, MBA-level course, averaged 15 students per semester. A persistent issue was that, even with in-class exercises to develop theoretical understanding, students were often unable to analogize to real-world situations. By introducing problem-based learning (PBL) the instructor broadened the teaching methods by introducing a consulting project for a local food bank to complement course work. The food bank's warehouse had been open for six months but had already become unwieldy to manage. Course readings, lectures, and in-class Lego assembly exercises provided the scaffolding for building students' mental frameworks. Then their frameworks were tested and reinforced through the consulting engagement enabling them to learn more than each alone could provide. PBL techniques described here can apply to any class teaching complex problem analysis.

INTRODUCTION

Many undergraduate and MBA students have had little exposure to the principles of Lean or the Toyota Production System (TPS). Without a contextual basis on which to build, getting the students to understand Lean theory and new skills that apply that theory in a single semester are daunting tasks. Further, traditional teaching methods rely heavily on manufacturing experience and assembly techniques. For instance, classroom exercises can be used to build some object as a way to facilitate theoretical application, such as Lego cars, kites, paper airplanes, clocks, etc. Over the past few years during which this MBA-level class has been taught, the student demographics and lack of work experience required modifying teaching style and examples used.

The Lego car assembly approach, with 15 assignments throughout the course, has been used by the authors with over 80 students over the past four years with consistent success. However, students often experienced problems applying the Lego-learned concepts outside of the classroom. This problem was pronounced at the part-time MBA level because those students who typically worked expected to transfer what they learned to their jobs. Therefore, as part of a course redesign, it was decided not to abandon the Lego car assembly because of the extremely positive student responses and the controlled atmosphere in which it takes place. In addition, to bridge the analogical gap between theory, case, and actual practice, a problem-based learning (PBL) approach in the form of a project for an external customer was added to the class so that students would experience the application of Lean in a real-world setting. The objectives and deliverables of an MBA-level Lean Six Sigma class, during the spring 2012 semester, were expanded to include a consulting component at a local non-profit food bank. The goal of combining these two elements of the class is to provide a basis for applying Lean principles to both the Lego car assembly and the real-world, consulting project. The unique quality of this approach was the evolution of students' fledgling, mental frameworks that were reinforced through failure and re-synthesis by their application of knowledge to a consulting situation.

BACKGROUND

Bennis and O'Toole (2005) noted that students today are ill equipped to deal with complex, unquantifiable issues after they leave college and that today's teaching environments fail to provide students with the knowledge of how to be 'fact integrators' rather than 'fact memorizers'. To combat these issues the classroom environment has been moving beyond lecturing toward experiential learning (Kolb, 1984f). As this trend has evolved, instructors have applied new methodologies to the classroom to engage the students beyond the 'sage on the stage' model (King, 1993). A common pedagogical technique is to use case studies to expand the horizons of the classroom to include more real-world situations. However, real-world problems are best applied when the students already have some grounding in theory and its application. In addition, there are limitations to the complexity of problem that can be addressed in a classroom, regardless of how sophisticated or well-written a case study might be.

From our experience, the use of case studies is further exacerbated because fewer students have manufacturing experience, which is the typical framework providing foundational topic knowledge. In addition, students from service industries rarely comprehend processes or wastes that as they apply to service jobs.

Thus, when teaching Lean and TPS concepts, the case study method is a poor choice because students lack the both physical and conceptual foundations. In addition, as with many other fields, there are several other skills objectives for applying Lean to be learned, such as value-added analysis (VAA) and root cause analysis (RCA), and teaching these skills from a book is difficult.

To counter this lack of contextual foundations, Lean classrooms have used Lego car assembly (Rosen & Rawski, 2011) as an effective medium to convey the basic aspects of Lean and TPS, and the need for flexible modularity of work to typify implementation issues.

A similar issue has been encountered in medical schools that found that the traditional lecture model failed to impart the contexts and interdependencies that doctors encounter (Donner & Bickley, 1993). Problem-based learning (PBL) was developed to help the students understand medicine from a more holistic viewpoint (Schmidt, Rotgans, & Yew, 2011). Two distinguishing aspects of PBL, from the instructor's perspective, are the open-endedness of the problem and the lack of direct guidance (Hmelo-Silver, 2004). The second, and probably most difficult for the typical instructor, is the change in their role from direct guidance to tutoring. PBL uses tutors or coaches that are available when the students need assistance. However, tutoring assistance is not to 'teach' but to clarify ideas, and review the thought and task processes. The student's job is to identify what they don't know, find the pertinent information, and teach themselves.

In conjunction with tutoring, the instructors role is to help provide the students with *scaffolding,* methods of practical application of theory (Hmelo-Silver, 2004). Scaffolding acts as a support mechanism around student topic exploration. PBL problems are recommended to be ill-structured, not have a single solution, and have the information to solve the problem unavailable at the outset. Thus, students need to iteratively work towards a solution (Hmelo-Silver, 2004).

In addition to the problem characteristics, one of the key components of PBL is the understanding of what the problem solvers do not know and how to acquire the knowledge. This knowledge gap is one of drivers of the learning process because the students must frequently revisit their assumptions and hypotheses about the problem, state of current information about the problem, frame and reframe the problem as necessary, ask the appropriate questions, and assess the knowledge gap again. This iterative process reinforces the tenets of Lean and TPS better than can be accomplished in a classroom environment.

INNOVATION

This teaching approach is innovative in several ways. First, by coupling in-class exercises with the consulting project, students were forced to create solutions that moved them beyond the classroom, resulting in learning that could not be replicated through other classroom exercises. Second, because of food bank constraints, students had to discuss alternatives in terms of how successful each might be in the food bank environment. Thus, recognizing that compromises on the ideal solution were needed to develop recommendations that fully met the customer's needs fostered probing discussions that were unlikely with just classroom exercises. Third, course risk to students is that they fail to internalize new skills because of preconceptions. A real-world project, such as warehouse management, forces students to deal with their biases through the discussion of alternatives and what would work in a client environment, thus facilitating students' analogizing processes. Finally, real-world projects are innovative because they force discussions that might otherwise not be held. Rarely do students have the opportunity to analyze an entire warehouse operation with multiple value chains with varying needs. As a result of this project, more class concepts and potential recommendations were part for the discussions than would otherwise have been the case.

Live projects are not without risk to the professor because they require significant improvisation in dealing with both the client and staff at the project organization, and the students in the live situation. The risk to students is that they may not outgrow preconceptions to apply new skills to the project. This is more likely with classroom-only exercises because students can conclude the exercises successfully while failing to analogize to work situations. A real-world project forces students to deal with their biases through the discussion of alternatives and what would work in a client environment, thus facilitating students' analogizing processes.

Real-world projects often force discussions that might otherwise not be held. While Lego exercises provide discussion and understanding of complexity, the need to compromise for a given context or requirements is missing from that type of learning. This particular combination of Lego + PBL project was innovative because rarely do students (or professors) have the opportunity to analyze an entire warehouse operation with multiple value chains with varying needs. As a result of this project, more class concepts and potential recommendations were developed than would otherwise have been the case.

Client management and project management are skills that often are not taught because of course constraints. As a result, of live projects, students gain these valuable skills as well as the typical alternatives analysis skills from the in-class exercises.

IMPLEMENTATON

Lego Car Assembly

The Lego car assembly has been used for the past four years in a variety of mixed undergraduate/MBA and MBA classes. The following description is for one MBA class, but the basic structure differs little from the mixed classes.

The purpose of the Lego car assembly exercises in the classroom is to provide a stable environment for students to begin to understand the basic principles of Lean. The Lego car, seen in Figure 1, is used throughout the semester with variant models introduced in the later part of the semester with two of the 13 variations shown in Figure 2. The students are assigned to groups of 5-6 students and divide the work among a group of material handlers and assemblers. The students' goal is to build as many cars as possible in an 8 minute build with as little excess inventory as possible. The exercise is summarized in Appendix A. They main metric for each 8-minute build is the total revenue from each completed car less the costs of materials, labor, and left over inventory. An example of the scoring sheet is in Appendix B. The team with the most revenue is the 'winner'.

Figure 1 – Typical Configuration

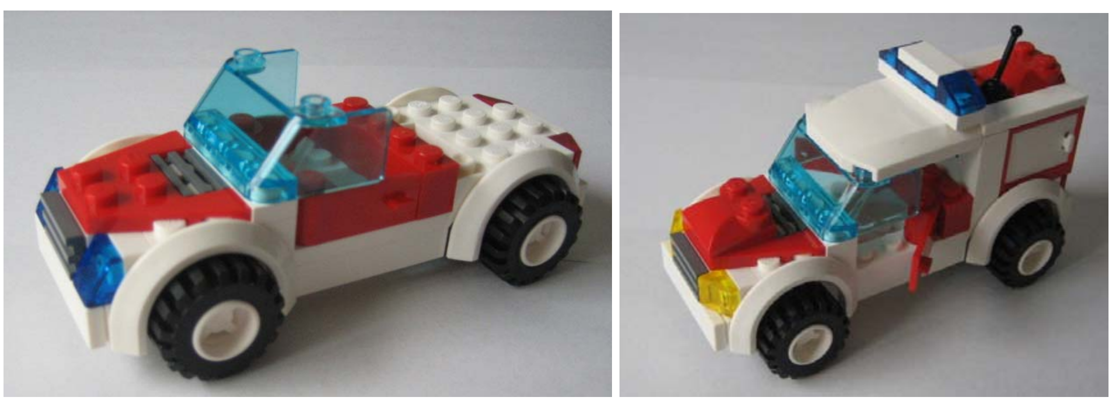

Figure 2 – Variant Designs (2 varients out of 13 total)

During the first several weeks of Lego building exercises, students begin to ‘see’ the wastes in their systems and apply Lean principles to their assembly process. The concepts learned include: flow, waste identification, push vs. pull, work balance, and achieving single piece flow, takt time development, kanbans, visual factory, quality at the source, and quick changeovers when variations are introduced (Dennis, 2007; Naylor, et al., 1999; Tajo, 2008). These concepts are detailed in class lectures and readings, which are designed to occur at approximately the same time that the students typically experience those problems in their Lego builds.

The typical Lego configuration builds take place for approximately two-thirds of the semester, which is about the time it takes for students to begin to master the process. Then, 13 variants of the model are introduced to ‘break’ student systems and force them to redesign their processes to accommodate each variation. These changes create a knowledge gap that students work at overcoming for the remainder of the semester. As a note, they are warned after the first build in the second week of the semester that the variation will take place and that they should be designing their systems for flexibility. Some of the variations are slight, such as swapping head light colors, and some are radical, such as a requirement that finished cars use 50% of the parts previously used. Variations from design changes cause the students’ systems to force design system failure requiring subsequent correction. As is often said by the Professor, “Only when you break something, fix it, and keep it fixed are you sure that you have made a better system.”

The most difficult issues for every group are information flows and communication. At the beginning of each semester, students expect the physical assembly of the cars to be their top issue, but they are warned repeatedly that this is a minor issue and that they need to focus much more effort on their ability to transfer information. Invariably, about half way through the semester, they realize that without information, the best assembly systems are useless unless they know what they are building and what everyone around them is doing. More is said about this point during the PBL portion of the paper.

To reinforce the learning process, each individual and each team submits written reflection papers on the Lean issues that they learned and what needs were to be addressed for each build. This task makes the conceptual aspects more explicit by codifying the issues. Also, shortly after the builds begin, there is a lecture on root cause analysis and the students must also include a minimum of one RCA for each of their reflection papers. It has been noted that the typical student has little understanding of the difference between symptoms and causes, so this exercise gives them a tool that remains useful throughout their careers.

PBL Consulting Project

The PBL consulting assignment took place at a local non-profit food bank that consolidates food donations, sorts and segregates the donations, and then distributes them to local food pantries and soup kitchens. This project was selected because it had some ambiguous and poorly defined aspects of the food bank’s inventory control, warehousing, and food distribution processes. The food bank understood that their internal processes were not adequate, but had little understanding of how to proceed in fixing the problems. From a PBL perspective, this situation was ideal because the client did not know the information, nor did they have the knowledge about what was needed to fix the problem. This met the criteria of both Bennis and O’Toole’s (2005) complexity and ill-defined problem and PBL’s open-ended solution. Because of these conditions, the students had to complete several cycles of assessing their knowledge gaps and obtaining the necessary facts.

Students were split into two groups to focus on warehousing-inventory management and the food donation sorting process. Breaking the problem into sub-projects insured that the teams had adequate time to complete their projects and not be overwhelmed by the scope of the food bank problems.

As stated previously, the instructors had to shift their mind set from being the ‘sage on the stage’ (Donnelly, 2006; Hmelo-Silver, 2004; King, 1993) to become a tutor in the process. It would be easy to jump into the learning process and show the students a solution to the problem, but this short-circuits the PBL process and does not allow the students to learning in their own way. The most frequent tutoring item was helping the students identify their knowledge gaps and assisting them in developing strategies to close the gaps. At the beginning of the projects, most of the students had never been in a warehouse or involved in a sorting process, beyond a tour, and did not know enough about the situation to understand which questions to ask.

EFFECTIVENESS AND BENEFITS OF PBL LEARNING APPROACH

The goals of the PBL approach were to provide a mechanism to transfer the learning taking place in the classroom to a complex and ill-defined problem in the real world. Conducting the PBL project without the scaffolding of the lectures, readings, and Lego car assembly would have been more difficult and less rewarding to the students. The learning outcomes and the resulting scaffolding were effective as, in the words on one of the students, “the projects were useful and completely related to the course material since the key to maximizing profits is to minimize waste, which is the basic principal of lean.”

The Lego car assembly and the PBL project were concurrent activities. Following the guidelines of the PBL method, the professors did not give solutions during the visits to the food bank. However, the principles of Lean are universal and are easily transferred from one setting to another. Therefore, during the Lego builds potential solutions would be subtly reinforced to nudge the students into seeing the boundary spanning solution. Class concepts reinforced during every build and during class lectures related to the need for accurate and timely information flows, using the KISS (Keep It Simple Stupid) principle in developing solutions, and designing solutions that act on information while it is being created or known.

Continuous reinforcement created a drumbeat of these items that became apparent during the later visits to the food bank. During one visit, a student had the observation that the problems that they were trying to grasp were the exact same problems that they were trying to solve in the Lego builds. The issue evolved around how to use visual communication during the variation builds to let the assemblers know what vehicle they are building. The solution that was developed was to color code each of the variations and all subsequent items, e.g., training documents, kanbans, etc. The sorting area of the food bank had the same issue in that multiple varieties of foods that could be identified using the same solution. Once this watershed event took place, the students began to see that the solutions for one context could be the solution for the other. See Figure 3 and 4 for an example of the crossover.

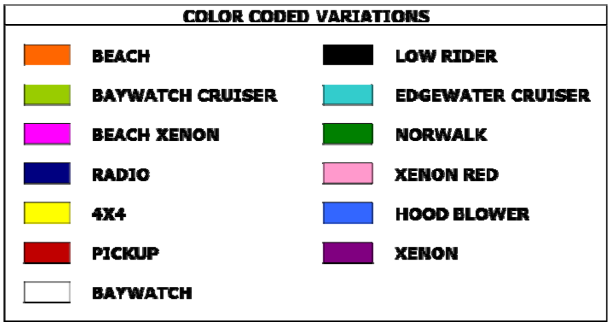

Figure 3 Color-coded Sheet for Lego Variations

Figure 4 Color-coded Sorting at Food Bank

Students also learn that applying lean to a large scale project may result in waste remaining in the system. One teaching point during the Lego builds is that a system will rarely be in perfect balance, but with a small system, it can come close. In the food bank, the complexity quickly made any attempt at balance a quixotic endeavor. However, this lesson was hard for students to grasp because from their success in applying the color coding to the sorting area (see Figure 4), they thought that most other learning points would transfer as well. With tutoring, they were eventually able to identify the key bottleneck operations at the food bank and design solutions to ensure the waste in these areas was minimized while the waste somewhere else was not touched.

A critical class theme relates to information management and the ability to transfer information during hand-offs. A lack of appreciation for information management repeatedly drives difficulties during the Lego builds and the students struggle with it. During the second visit to the food bank, one student who had been performing root cause analyses about this problem with his Lego team made the comment, "This is just like the Lego cars on a larger scale." His realization led to a solution at the food bank for the labeling of the inventory to maintain integrity during transfers to the warehouse. This solution created scaffolding from the food bank back to the classroom because the student successfully transferred the solution to their Lego builds. This outcome was extremely encouraging about the effectiveness of learning as the students became aware of the applicability of their new knowledge.

Evaluation Plan

The evaluation of projects included on-site reviews, group discussions, individual reports, and client acceptance of solutions. The first phases of evaluation included on-site review meetings and group discussions. To gather information, the students visited the food bank five times, conducting Gemba walks, mapping the operations, and interviewing the staff. During the visits, the students identified their knowledge gaps and consulted with the instructors, who were present at all of the visits, for necessary tutoring. During each visit, students discussed potential solutions, reevaluated their assumptions and knowledge, and collected more information. These iterations allowed for critical analysis of the recommendations for their adequacy in meeting the food bank's specific needs. The professors monitored progress of the iterations to ensure that progress towards the project's completion was being made.

The second phase was individual reports allowing each student to present their own unique perspective and ideas to recommend changes. After reports were graded, a group discussion was held to discuss the best ideas from each student and create a unified solution to the problem. Selecting this order of submission created more work for the instructor, but the quality and creativity was better than a single report was likely to generate. Further, the two-step reporting process allowed each student to have a voice and kept dominate student(s) from having too great an influence. Solutions generated in the individual reports, when aggregated, improved over recommendations generated during the food bank visits.

The last test of project effectiveness was the client accepting and implementing the recommendations. The final report to the food bank was an unqualified success as the entire set of student recommendations was agreed to enthusiastically and scheduled for implementation. The effectiveness of the students' impact on the food bank was evident during the later on-site sessions as they noticed that the preliminary recommendations that had been reviewed with the floor personnel and management already had been implemented. From the students' perspective, these implementations were the most sincere complement that they could have received by seeing that their ideas had value and were helping the food bank to improve its operations.

Educational objective success

As stated above, the educational objectives was to create scaffolding from the classroom to the PBL project utilizing Lean Six Sigma, 5S, DMAIC, VAA, RCA, etc. This objective was met as evidenced by the students' transfer of knowledge from the classroom to the food bank setting. The success of this innovation exceeded the initial objective of improved student integration of material as evidenced by the implementation of the complete set of recommendations. The underlying objective, though not explicitly stated at the outset, was to engage the students in a project that provided them with the opportunity to apply their knowledge and create a passion for the topic as evidenced by the comments from a student, "This (the food bank project) was useful and really helped in learning how to apply the material."

TRANSFERABILITY AND IMPLICATIONS FOR EDUCATORS

The coupling of the synergistic aspects of controlled experiential learning in the classroom and applying the learning in a PBL-based project has many applications outside of Lean. Our experience reinforces the use of scaffolding or other appropriate frameworks through which students can learn in the relative calmness and stability of a classroom. Then, given the selection of a project that is properly complex, the students can combine these two learning environments to learn more effortlessly to apply theory to practice, adjusting for contextual specifics.

Projects are most successful when they are well contained or have a small solution space for potential outcomes. This type of project can be selected for many reasons: 1) there is a fear that the students won't be able to find a solution to the problem, 2) ill-defined problems will be difficult to solve, or 3) it is easier to teach during the project than to act as a tutor. Before this project and the success that was achieved, many of these arguments held as professors, we worried about these issues. But, after witnessing the scaffolding success in student application of concepts to the PBL project, these fears have been alleviated.

Two important caveats must be made about the selection and management of the projects to use: scale and scope. The complexity of the problem and the potential solutions must be closely coupled to a written statement of work because it is very easy to confuse the scale and scope of work. For example, while originally negotiating with the food bank, we had agreed on the two projects described above. At outset of the negotiations they wanted the project to include the coordination and communication between two facilities, but with the limited amount of time, enrollment in the class, and time required for the students to direct themselves through the numerous knowledge gaps they would face, there would not be enough time to complete that project. The complexity of the solutions in one of the facilities was adequate for the needs of this project. So, care in project definition is required to meet pedagogical goals while also solving client problems but without committing to trying to solve all client problems in a single semester.

The second caveat deals with expansion of the scope of work, often referred to as mission creep. During the first several weeks of the project the students were suggesting solutions to the various issues and the management of the facility realized the value of the project. They asked for the project to be expanded to another area of the facility that was experiencing similar problems. However, this request was turned down for two reasons: time remaining in the semester and more importantly, the students were succeeding and it was decided that the additional scope could jeopardize both their learning and the quality of the project outcome. If the scope is too large, student stress reaches a point at which they get frantic to get to any solutions rather than trying out different ideas from the class to see which might apply and how. As with any project such as this there is always the desire to please the client for a variety of reasons, but the ultimate goals are the student learning and quality of client outcomes. Therefore, both scope and scale need to be balanced and managed by the professor in developing project definitions that optimize student learning.

SUMMARY

This paper describes the use of problem-based learning for MBA-level course and its application. The course taught Lean Six Sigma and Toyota Production Methods, including Gemba walks, root cause analysis, value-added analysis, definition of inventory models, push-pull inventory management techniques, and information management. The goal of the projects was to provide a means for students to learn how to analogize from classroom learning to practical situations. By using readings, lectures, and in-class, Lego-build projects as scaffolding, the students performed a consulting engagement with a local food bank as a PBL exercise.

The project outcomes were successful for students who were able to apply theory to practice, and critically evaluate and compromise on solutions that fit the context. As a result of the PBL project innovation, students engaged in discussions they would otherwise not likely had and were able to successfully develop solutions for warehouse management of the food bank. We recommend this approach to other professors teaching relatively abstract subjects to greatly enhance their students' learning.

References and project description are available on request.

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