Problem-Based Learning Applied to Student Consulting in a Lean Production Course

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Students often experience difficulty applying course techniques to real-world situations. Problem-based learning (PBL) helps students apply course material to facilitate the transfer of knowledge to practical use. This research describes a student consulting engagement to analyze a local food bank's warehouse operations using PBL tenets to guide the process. In the course of the consulting commitment, students developed solutions that met food bank goals, while applying course theories and skills. When coupled with the hands-on, in-class exercises, the consulting engagement provided a positive learning experience for students and is recommended for effective transfer of skills to practice.

INTRODUCTION

This research sought to apply problem-based learning to a Lean Six Sigma class to improve students' ability to apply class concepts as part of a consulting exercise. Many full-time and working, part-time MBA students have little exposure to the principles of Lean Six Sigma or the Toyota production system (TPS). This lack of exposure is even more evident in the traditional undergraduate student whose industrial work experience was usually limited to a summer internship. Further, traditional books and teaching methods rely heavily on manufacturing experience. Without a contextual basis on which to build, helping the students to understand Lean Six Sigma theory and the corresponding skills in a single semester is a daunting task for though students often understand the principles, applying them outside of the classroom is a challenge. This problem is frustrating to students because those who are working at the time of the course expected to transfer what they learn to their jobs immediately. Further, over the past few years during which the Lean Production class was taught, the number of students with manufacturing work experience decreased, calling for a modification of the teaching style and platforms used to compensate for this lack of experience.

The issue was how best to bridge the analogical gap between theory, case, and actual practice. The solution was to add the problem-based learning (PBL) approach to the class in conjunction with the consulting project. The goal of combining these two elements was to provide a basis for applying Lean Six Sigma principles to both a series of Lego exercises and a 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 both the Lego exercises and the consulting situation.

This paper illustrates how Lego exercises, when coupled with PBL, provided a useful framework for students to transfer their knowledge from the classroom to a consulting project. First, the literature of PBL and experiential learning are discussed to show how these methodologies create an appropriate base of knowledge, or scaffolding, to ensure that students can create an appropriate mental model to successfully complete their projects. Next, the Lego-block projects and the transfers of knowledge between the classroom and the consulting project are described. Finally, the consulting project, its assessment, and its outcomes are described.

PROBLEM-BASED LEARNING

Bennis and O'Toole (2005) note that students are ill equipped to deal with complex, unquantifiable issues after they leave college. They argue that teaching environments fail to provide students with the knowledge of how to be 'fact integrators' rather than 'fact memorizers' (Bennis, et al., 2005, p. 101). To combat this issue, the classroom environment has been moving beyond just lecturing to experiential learning (Kolb, 1984). As this trend evolves, instructors apply new methodologies to the classroom to engage the students beyond the 'sage on the stage' model to the 'guide on the side' model (King, 1993).

PBL encompasses a series of techniques that provide common characteristics such providing applied, participative, interactive, and whole-person emphasis on the experience and giving students contact with the environment, ensuring problem variability and uncertainty, scheduling structured discussions of student findings, including student evaluation of the experience, and providing feedback to participants (Clark et al., 2010; Gentry, 1990; Itin, 1990). PBL covers a wide range of in-class and real-world exercises including assessment centers, forums, group discussions, panel meetings, writing experiences, student-written textbooks, computer assisted instruction, in-class cases, COMPUSTAT tape usage, communication workshops, Delphi forecasting, time management sessions, game show formats, learning cooperatives (where students take the responsibility for teaching themselves), internship programs, job search preparation, on-the-job training, field trips, and live cases (Gentry, 1990, p. 17-18).

The design of the experience is crucial to its success as weaving variability and uncertainty into, for instance, Lego exercises, requires significant thought and planning. Yet, variability and uncertainty provide an effective means for students to test their mental models and understanding of techniques while also offering a way to extend them at the same time. Further, in moving beyond the 'sage' teaching method, instructors must be able to expertly and quickly analyze what students are doing and how they are thinking in order to imbue structured discussions of the situations with the mentoring and guidance when needed to shift their thinking.

Students, through evaluating their PBL experiences, clarify what they have learned and also, lingering uncertainties. This leads them to both solidify their mental model with new information and stay open-minded about remaining uncertainties. Mentoring feedback occurred throughout the process and at the conclusion of the consulting project. Feedback served to reinforce knowledge learning and identifies areas on which to further concentrate learning efforts.

PBL does not mean abandonment of lectures. Rather, the instructor's role is to help provide the students with *scaffolding* (Hmelo-Silver, 2004), background information that supports their exploration of the topic they are trying to learn. Scaffolding is the theoretical, skill, and practical application of theory relating to the problem area for the PBL exercise (Hmelo-Silver, 2004). Such scaffolding is developed through lectures and reinforced and matured through sensitivity testing done within the PBL exercises (Argyris, 1980; Christenson et al., 2009; Hmelo-Silver, 2004).

One of the most common PBL techniques is case studies that expand beyond the classroom to simulate a real-world situation. However, cases are best applied when the students already have solid grounding in theory and its application. In addition, there are limitations to the variability and complexity of problems that can be addressed through classroom case analysis, regardless of how sophisticated or well-written a case might be (Argyris, 1980).

From our experience, the issue of using Lean Six Sigma case studies is further exacerbated because fewer students have manufacturing experience, which can be beneficial in completing this type of case. Thus, their difficulties stem not only from failure to properly analogize but also from failure to completely understand the case and its implications. Further, students who work in service industries are typically not familiar with Lean Six Sigma or TPS concepts and the wastes that exist in service jobs. Thus, the case study method is a poor choice for Lean Six Sigma concepts because students lack the conceptual foundations needed to derive meaningful solutions. In addition, as with many other fields, there are several skill objectives used in applying Lean Six Sigma and TPS tenets that need to be learned, such as value-added analysis and root cause analysis, and learning these skills without practicing them is difficult.

To counteract students' lack of contextual foundations, Lean Six Sigma classrooms have used Lego exercises for a number of years (Rosen et al., 2011). From an experiential learning standpoint, Lego building exercises were a more effective way to convey the basic aspects of Lean Six Sigma than lectures alone (Kolb, 1984). However, the complexity demonstrable through Lego exercises was limited because classroom scalability does not support all of the interdependencies with implementations present in a real-world application. For instance, policy, human resource, or physical environmental limitations cannot be explored (Argyris, 1980). Further, there was no means to question what was being done or the materials being used. Thus, issues of supply and its sources were not considered.

A similar teaching dilemma is encountered in medical schools, as they found that the traditional lecture model failed to impart the contexts and interdependencies that doctors encountered (Donner et al., 1993). In response, PBL was developed to help students understand medicine more holistically (Schmidt et al., 2011). In order to provide this holistic viewpoint, problems need to be adequately complex. Thus, PBL advocates recommend that the problems be ill-structured, not have a single correct answer, and have insufficient information to solve the problem the outset (Hmelo-Silver, 2004). This problem structuring requires students to iteratively work towards a solution as new knowledge gaps are discovered and rectified (Hmelo-Silver, 2004).

Knowledge gaps are one of drivers of the PBL process because the students must revisit their assumptions and hypotheses about the problem. Therefore, they need to assess the state of current information about the problem, frame and reframe the problem as necessary, ask the appropriate questions, and assess their knowledge gaps. This iterative sequence reinforces the tenets being taught. In the case of Lean Six Sigma, when coupled with the Lego exercise and consulting project, such reinforcement enhances student ability to be a fact integrator better than lectures alone.

Two distinguishing aspects of PBL, from the instructor's perspective, that enable a holistic viewpoint to be conveyed are the open-endedness of the problem and the lack of direct guidance (Hmelo-Silver, 2004). PBL emphasis on the role of guidance is for the instructor to act as a tutor or coach when the students need assistance. As a result, this assistance is only to clarify ideas and review the thought and task processes. The student's job is to identify their knowledge gaps, find the pertinent information, and teach themselves.

Applying Kolb's (1984) experiential learning loop iteratively built and reinforced the scaffolding. Kolb recommends that students complete four phases of learning to assist them in acquiring their new knowledge:

1. Concrete Experience – being involved with what is occurring in the here and now; an in-class exercise for example
2. Reflective Observation – understanding the meaning of the learning experience through observation and impartial description of different perspectives
3. Abstract Conceptualization – using logic, ideas, and concepts to build general theories about their experiences and develop new perspectives
4. Active Experimentation – making changes by applying new general theories to personal situations

These phases can be implemented in the classroom through a variety of methods. A common method for phases 1 and 4 for Lean Six Sigma is a Lego-block building exercise; phases 2 and 3 can be accomplished through reflection papers (Reynolds, 1998). All of these were used throughout the class.

LEGO-BLOCK BUILD EXERCISES

At the time of this project in 2012, the Lego exercises had been used for four years in a variety of mixed undergraduate and MBA classes. The exercises provided an experiential learning framework that enabled the topics of the class to be reinforced through application. Also, by manipulating the conditions of the Lego exercise processes such as product variations many vital aspects of Lean Six Sigma could be introduced and the nuances and complexity of the topics could be explored more thoroughly. The Lego exercises were conducted in 7 of 12 class meetings and accounted for approximately one-third of the class meeting time.

The purpose of the Lego exercises was to provide a stable environment for students to begin to understand the basic principles of Lean Six Sigma. Exercises to build Lego cars (Figure 1) were used throughout the semester with progressively more complex models introduced in later exercises (Figure 2). The students were assigned to groups of 5-6 students. The students' goal was to build as many cars as possible in an eight minutes with as little excess inventory as possible (See Appendix A). The overall metric of success for each eight minute session was the total profit, calculated as total revenues less the costs of materials, labor, and inventory (See Appendix B).

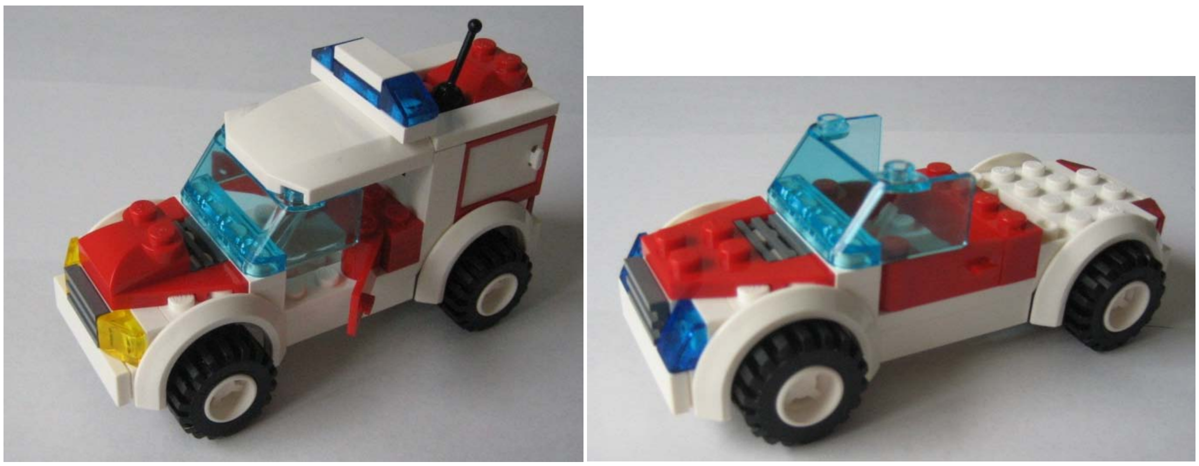
FIGURE 1
TYPICAL LEGO-BLOCK BUILD

The students had many degrees of freedom when creating and implementing Lego solutions. The only rules students were required to follow were:

1. Only one person may do any given assembly operation
2. Assembly and warehouse materials must be physically separate
3. Once material has been pulled from the warehouse, it must be accounted for as an inventory cost.

Rules ensured that problems and issues occurred during the assembly processes. For instance, if an assembler had too much work to accomplish in eight minutes and no one to help them out, the first rule forced the team to assess team workflow balancing. The second rule prevented *supermarkets* that eliminate inventory, thus increasing the level of information flow and communication that must take place for students to implement just-in-time inventory (Liker et al., 2006). The last rule ensured that problems with just-in-time inventory and single piece flow could not be ignored without paying a price in their team ranking and grade. Students were warned after the first exercise that variations would occur and that they should design their systems to accommodate change. As was often said by the professor, “Only when you break something, fix it, and keep it fixed can you be sure that you have made a better system.”

FIGURE 2
VARIATIONS OF LEGO-BLOCK BUILD DESIGNS



During the first several weeks of Lego exercises, the students began to see the wastes in their systems and began applying the principles of Lean Six Sigma learned in readings and lectures to Lego assembly processes. Their typical learning points were: flow, work balance, TAKT time (i.e., cycle time), kanbans (i.e., scheduling), visual factory, quality at the source, waste identification, push vs. pull inventory, achieving single piece flow, and quick changeovers for variations (Dennis, 2007; Naylor, et al.,1999; Shahram et al., 2011). These topics were overlaid onto the Six Sigma define, measure, analyze, improve, and control (DMAIC) processes (McCarty et al., 2005) and the Deming Cycle: plan-do-check-act (Gupta, 2006). These learning points were detailed in class lectures and readings, which were structured to occur at approximately the same time that the students typically experienced those problems in their Lego exercises.

The typical configuration (Figure 1) was used for approximately the first half of the semester, which was about the time it took for students to begin to master the process. Then, 13 variants of the model to be built were introduced to ‘break’ the team’s process, forcing them to redesign their information management and process to accommodate variations. Some of the variations were as slight as the headlights swapping colors with the light bar and some were radical, for instance, a requirement that finished cars use 50% fewer parts than the original configuration (Figure 2). The purpose of the variations was to cause the teams’ systems to be placed under the maximum pressure thus forcing failures and subsequent corrections. The variants forced students to identify knowledge gaps that they worked at bridging throughout the semester.

In particular, the most difficult issues for every team were information flows and communication. At the beginning of each semester, students expected the physical assembly of the cars to be their key issue. They were warned repeatedly that this was minor and that they needed to focus much more on their ability to transfer information. Invariably, about half way through the semester, students would realize that without information, the best assembly systems were useless unless they knew what they were building and what everyone around them was doing. This concept was further explored during the PBL consulting assignment discussions.

PBL CONSULTING ASSIGNMENT

Methodology

The consulting assignment took place at a local non-profit food bank that consolidated food donations, sorted and segregated donations, and then distributed them to schools, local food pantries and soup kitchens. This project was selected because it met many characteristics desired for PBL (variability, uncertainty, no clear answer, and whole-student engagement). Because the food bank exhibited needs that could be addressed by application of class teaching -- poorly defined processes for inventory control, warehousing, and information flows. The food bank understood that their internal processes were not ideal, but had little understanding of how to proceed in fixing its problems. From a PBL perspective, this situation was ideal because the students would need to identify their knowledge gaps and those of the food bank and iteratively work towards open-ended solutions. This process also met the Bennis and O'Toole criteria (2005) for students to become fact integrators. As a result of these conditions, the students completed several cycles of assessing their knowledge gaps and obtaining the necessary facts, steps that could only be done by integrating course concepts into their thinking.

The two student groups worked on separate but related issues: warehousing-inventory management and a non-perishable food sorting process. Dividing the problem into two sub-projects insured the teams adequate time to complete their projects without being overwhelmed by the scope of the food bank problems.

The PBL structure required the instructor to shift from being the 'sage on the stage' to tutor (Donnelly, 2006; Hmelo-Silver, 2004; King, 1993). During the project, it would have been easy to lead the learning process and show the students a solution to the problem, but this would have short-circuited the PBL process and would not have allowed the students to learn in their own way (Argyris, 1980; Hmelo-Silver, 2004). The most frequent tutoring topics were helping the students to identify their knowledge gaps and directing them to developing strategies to close the gaps in a way that fully met food bank requirements. For example, at the beginning of the projects, most of the students had never been in a warehouse or involved in a sorting process, and they did not know enough about the situation to understand which questions to ask.

Several tutoring sessions went beyond Lean Six Sigma topics and dealt with processes for collecting information. During the first visits to the food bank, it was observed that the students did not accurately capture what they observed. For example, after the students interviewed an employee who oversaw the shipping dock the instructors debriefed the students. What students had taken away from the interview and what was actually taking place on the shipping dock were two separate things. The first impulse of the students was to suggest that the employee had given false information. In fact, the employee had relayed his belief of what was happening as he saw it. This situation was an important teaching moment to show the students that they always needed to compare what was told to them and what was actually happening. In other words, their interview discussion should have been coupled with observation with equal credence give to both. Through the tutoring, students were helped to see that inconsistencies shown in this situation occurred in other places as well. This led to discussions of techniques to rectify the inconsistencies and topics such as triangulation of information sources, constantly questioning what they knew and did not know, and effective interviewing about inconsistencies.

Transfers Between the Classroom and the Food Bank

The goal of the PBL approach to the consulting engagement was to provide a mechanism to transfer the learning taking place in the classroom to a complex, ill-defined, real-world problem. Lectures provided the scaffolding, the Lego exercises provided initial technique practice, and the consulting project provided the uncertainty and variability of the real world. The learning outcomes and the resulting scaffolding were effective as, in the words of one student, "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." Thus, by recommending ways to remove waste from the food bank processes, the student teams gave alternatives from which the food bank could choose for streamlining and improving its processes.

The Lego exercises and the consulting project were concurrent activities. The principles of Lean Six Sigma are universal and can be transferred from one setting to another; therefore, during the Lego exercises potential solutions would be discussed as a group to facilitate student understanding of potential boundary-spanning, food bank solutions. Lean Six Sigma concepts were developed in lectures and reinforced during every Lego exercise. The Lean concepts included the need for accurate and timely information flows, using the KISS (Keep It Simple Student) principle in developing solutions, the need to address client needs, and designing solutions that act on information immediately. Following the guidelines of the PBL method, the professors did not give solutions during the visits to the food bank. Rather, students would spontaneously say, "We did this in the last Lego-build…" thus drawing the desired analogies and forcing a discussion of how what they had done with Lego blocks could be applied to the food bank situation.

The transfer of the concept of acting on information immediately provides an example. Students often did not act on information during the first Lego exercises. The initial process was hectic and the students would receive information, such as a request for inventory, and then go on to another activity. They then would forget about the initial request and consequently their performance suffered. After the students learned this lesson during the Lego exercises, they became aware that the food bank did the same thing. They would get a shipment in, place it in the shipping are, and then forget to move the inventory to the warehouse. Thus, the scaffolding being created in the classroom provided a basis for insights into food bank problems.

The information theme was a critical tenet of the class and a lack of understanding of its importance led to repeated difficulties during the Lego exercises and the food bank project as the students struggled with the concept. During the second visit to the food bank, one student who had been performing root cause analysis on a Lego problem commented, "This is just like the Lego cars on a larger scale." His realization led to a solution at the food bank for more detailed and visible labeling of the inventory before its 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 exercises. This outcome exemplified the effectiveness of learning as the students became aware of the applicability of their new knowledge.

Another example of this continuous reinforcement of the scaffolding 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 exercises. The issue revolved around how to use visual communication during the variation builds to let the assemblers know what vehicle they were building. The solution that was developed was to color code each of the variations and all subsequent items such as training documents, kanbans, etc. The sorting area of the food bank had the same issue in that multiple varieties of food boxes used in the sorts could be identified using a similar solution. Once this watershed event took place, the students began to see that many solutions for one context could also solve the other context. See Figures 3 and 4 for an example of the crossover.

Another key learning point for the students related to how the complexity of applying Lean Six Sigma to a larger scale resulted in waste still being in the system. One of the teaching points during the Lego exercises was that a system will rarely be in perfect balance, but with a small system, it might 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 embrace because, from their success in the Lego exercises and in applying color-coding to the sort boxes, they thought that most other learning points should 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 were minimized while the waste somewhere else was unchanged or could increase. Thus, a local increase of waste in one area actually could lead to lower overall waste in the warehouse.

FIGURE 3
COLOR-CODED SHEET FOR LEGO VARIATIONS

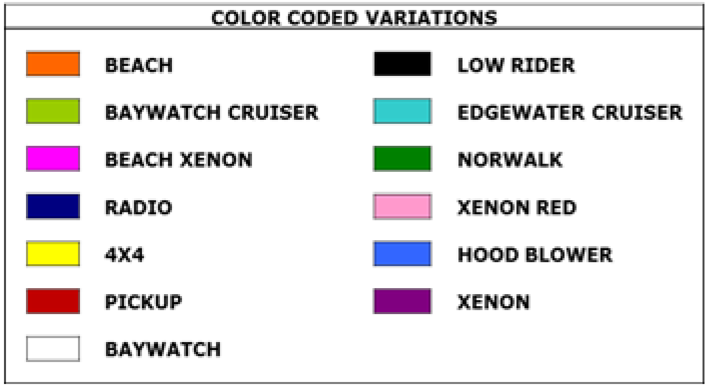


FIGURE 4
COLOR-CODED SORTING BOX AT THE FOOD BANK

Consulting Project Evaluation

Several types of evaluations were conducted during the course of the consulting project. First on-site team discussions were conducted at the end of every food bank visit. The second evaluation was based on individual reflection papers that included their analysis and recommendations of the food bank's issues. The third type of evaluation was a team paper to demonstrate group consensus on key issues and how best to address them. Finally, acceptance of the analysis and recommendations of the client were critical in providing feedback to the students. Each of these is discussed in this section.

The first type of consulting project evaluations were of on-site, group review discussions. To gather information, the students visited the food bank five times, conducting Gemba walks, mapping the operations, and interviewing the staff. During each visit, students discussed potential solutions with staff, 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. During the discussions, the students identified what they had learned during the present visit and remaining knowledge gaps. The professors sought to ensure that progress towards successful project's completion was made and attended the discussions to ensure needed tutoring took place. Tutoring was deemed necessary when either incorrect or inconsistent information were in danger of being accepted or when students were not sufficiently sensitive to food bank needs.

The primary purpose of the reflection papers was to complete Kolb's (1984) concepts of reflective observation and abstract conceptualization. A portion of each reflection paper was for students to connect the aspects of Lean Six Sigma to the Lego exercises. In addition to assessing student learning, the papers allowed insights into each student's thought process for the professor to better understand their progression in grasping course concepts. The papers then provided an ideal format for the instructor to apply PBL principles to coach students by critiquing their problem perceptions and solution analyses. Then, the reflection papers were shared with all of a student's team members. The individual reflection paper further provided less assertive students an opportunity to voice their ideas that might have been lost in a team decision process. By sharing the reflection papers, all team members were able to see each student's ideas and, hopefully, bring them to the group discussion for the team paper.

The team paper served a separate issue, and from our observations a more important one, of creating a consensus of what the key issues were and how to address them. The team assignment forced students to defend their ideas for improvement against those of the rest of the team. Through articulation and discussion of everyone's ideas, the teams gained further insights into the problem and the principles of Lean Six Sigma.

The last test of project effectiveness was the client acceptance and implementation the recommendations. The final report to food bank management was an unqualified success as the entire set of student recommendations was agreed to enthusiastically and scheduled for implementation. The effect of the students' impact on the food bank was evident during the later on-site visits as they noticed that the preliminary recommendations that had been discussed with the floor personnel and managers 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 were valued and were helping the food bank to improve its operations.

One month after the final report was delivered the authors conducted a post-project follow-up at the food bank. The manager mentioned that the food bank was ahead of their budget for the year by two million pounds of food delivered (out of a total budget of 10 million pounds) and were then on target to increase deliveries to 15 million pounds of food for the year. While the students' suggestions were not the sole reason for this increase, their analysis and recommendations had helped the food bank to understand its own knowledge gaps and had transferred some of their scaffolding to the food bank's employees. Some of the increase was attributed directly to student recommendations.

Educational Objective Success

The educational objective of PBL and the consulting project was to create scaffolding from the classroom to the food bank project thus, reinforcing decision processes and application of Lean Six Sigma tenets and related tools. The objective was met as evidenced by the students' ability to transfer their accumulated knowledge successfully from the classroom to the food bank problem. 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 develop self-confidence in the use of Lean Six Sigma. Project success exceeded the initial objective of improved student integration of material as evidenced by the food bank's implementation of the complete set of recommendations. In addition, student analogizing appeared to also have been successful by the following student comment, "This [food bank project] … really helped in learning how to apply the material."

Caveats in Project Selection

Two important caveats about the selection and management of potential projects related to scale and scope. The complexity of the problem and the potential solutions should be closely analyzed and detailed in a written statement of work prior to the class beginning. Both scale and scope of work should be considered. 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 also to include the coordination and communication between two facilities, but the professors deferred this aspect from consideration. In other words, the scope must be carefully managed. The allotted amount of project time should ensure adequate time for the students to navigate themselves through the numerous knowledge gaps they face. In the project described, had inter-location communications been included, project success likely would have been jeopardized. Therefore, careful, pre-class project definition ensured that both pedagogical and client goals could be addressed.

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, students suggested possible solutions to the various issues and the food bank management 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 with the current scope. It was decided that the additional scope could place at risk both their learning and the quality of the project outcome. If the scope had become too large, the students' stress level may have caused frantic, ill-considered 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 was always the desire to please the client for a variety of reasons, but the ultimate goals were both student learning and quality of client outcomes. Therefore, both scope and scale need to be balanced and managed by the instructor in developing project definitions that optimize student learning.

SUMMARY

This paper describes the use of PBL for an MBA-level course to successfully complete a Lean Six Sigma consulting project. The goal of the projects was to provide a means for students to learn how to create a mental model robust enough to allow them to transfer knowledge from classroom learning to practical situations. Through the application of PBL by using readings, lectures, and the in-class Lego exercise as scaffolding, the students performed a consulting engagement with a local food bank.

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, students engaged in discussions they would otherwise not likely have 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.

The synergy of coupling controlled experiential exercises in the classroom to a PBL-based project has many applications outside of Lean Production courses. The experience from this project reinforces the use of problem-based learning and scaffolding through which students learn in the relative calm and stability of a classroom. Then, a properly complex project can provide student an opportunity to apply theory to practice, and analogize and adjust their analysis to contextual specifics.

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APPENDIX A – LEGO-BLOCK PROJECT DESCRIPTION

Lego Competition

During the course of the semester, we will be using the Lego assembly as a hands-on learning exercise about the principles of Lean. During the course of the project we will have a variety of assignments and activities stemming from it.

During/after each run you need to collect the following data at a minimum:

- How many people assembled, handled materials, collected data, etc.
- Total pieces produced
- Total WIP (see WIP form), cost, where in process
- Detailed quality issues (assembly, material handling, where in process)
- Changes made to assembly, flow, # of people, material handling, etc.
- Disassembly times

Components of the Lego Project

1a. **Reaction papers (Individual)** – As we progress through the project, each time we have an in-class component of the project, you each will be required to turn in a 2-3 page (double spaced) reaction paper that covers the following items:

- Observations during the exercise
  - What was the lesson that was learned during the exercise?
  - What specific components of Lean came out during the exercise?
  - During the next exercise, what would you do differently based on the lessons learned? This needs to be specific action items
  - Any other observations, improvements, etc., for the next round
- Use of root cause problem solving for at least one issue per build (to be included after Root Cause Lecture)
  - This will be in the form of a 5 Why

Note: I don't want a recap of the data from each person: include this in your team report. You are welcome to include the data as it makes a point or illustrates the recommendations that you are making.

This paper is due on Mondays at 8:00 am (Use drop box on eCompanion for each build)

1b. **Reaction Paper (Team)** – Each team needs to submit an executive overview of:

- Basic information on performance (not limited to the following):
  - Number of vehicles built and variants
  - Disassembly quantity and time
  - Total profit/loss per round
  - Major issues for the build
- Detailed action plan for next build that is the consensus of the team; hence, why you submit a single team paper!!
  - Who, what, when, how

This paper will be due on Tuesdays at 8:00 am

- One representative from each team will e-mail this paper to me and cc the rest of the team

2. **Analysis of the Project** – During the project you will be analyzing the progress that is being made on implementing Lean. We will cover a variety of tools that you can use to analyze the project and plan for its improvement. Keep a team folder of all of your team meeting notes, team reflection papers, data, etc. This will serve you well as you write item #3. I recommend that you create a data keeper to manage this data set.

3. **Lean Report** – You will turn in a single-side A3 report (11"x17"). All of your critical information must be contained on the report of what you have learned, implemented, and results of improvements. (Warning, using small font for the report is not an option. All text must be at a minimum, 10 pt Times New Roman/Arial.) You can have supplemental materials and appendices, but these materials cannot be used during the presentation of the report.

Project Issues to be factored into the analysis

- The task was to build a car from 40 different parts.
- Car parts should be kept in a separate place (inventory) while car assembly is done in different table (factory).
- Each part has a value which is doubled when moved to the assembly table if the car was not built successfully. However, teams would make profits if they managed to build full cars.
- The group can allocate people as material handlers, assembler, or both. Each worker has a wage that is added to the overall cost, i.e., material handler $3000, assembler $5000, and combo (material handler and assembler in the same time $8000).
- To improve the flow, teams have to come up with a system and improve continuously, e.g., using visual aids to minimize missing/extra parts.

FIGURE B1
PARTIAL EXAMPLE OF LEGO-BLOCK ASSEMBLY REVENUE AND COST SHEET

WS - In any way)

Part	QTY	Picture	Assembly Step	Color	Cost	Total Cost per Car		WS1	\	WS7	WIP7	WS Inventory QTY	WS Inventory Cost	WIP Inventory QTY	WIP Inventory Cost
Axles	2			Grey	$500	$1,000						0	$0	0	$0
Axle Sub-plate	2			Black	$250	$500						0	$0	0	$0
Chassis	1			Black	$2,500	$2,500						0	$0	0	$0
Front grill	1			Grey	$175	$175						0	$0	0	$0
Top grill	1			Grey	$150	$150						0	$0	0	$0
Hood	1			Red	$500	$500						0	$0	0	$0
Front/Rear Sub-Bumper	2			White	$400	$800						0	$0	0	$0
Front & Rear Bumper (large)	2			White	$150	$300						0	$0	0	$0
Rear Bumper (small)	1			White	$100	$100						0	$0	0	$0
Rocker Bar	2			Grey	$375	$750						0	$0	0	$0
Windshield	1			Blue	$800	$800						0	$0	0	$0
Roof	1			White	$500	$500						0	$0	0	$0
Roof Support	1			Black	$250	$250						0	$0	0	$0
Door (Right & Left)	2			Red	$400	$800						0	$0	0	$0
Steering Wheel	1			Red/Black	$350	$350						0	$0	0	$0
Rear Seat	1			Red	$125	$125						0	$0	0	$0
Cargo Box Support	1			White	$100	$100						0	$0	0	$0
Cargo Box Support Post	2			White	$50	$100						0	$0	0	$0

APPENDIX C – PBL PROJECT REPORT DESCRIPTION

Implement Lean Six Sigma Report

Complete a minimum 12 page paper (Title, Bibliography, etc. do not count in page total) on the following:

- Description of what the process is and how Lean Six Sigma is a fit
    - Measurement and analysis of the problem that shows that you are treating root causes and not symptoms
- Current process state
- Ideal process state map
- Improved process map (map to be implemented)
- Identify the waste streams (people, process, inventory, etc.)
    - This class is also about supply chains, so identify supplier and customer issues
- Sources of variation and how to reduce them (this is the focus of the paper, so a large portion should be focused on this section) - DMAIC
    - Concrete and explicit ways to implement Lean
    - Specific implementation plan
    - How to monitor and control the improvements
      Include both short-term and long-term…They are different so have specifics for each
- Potential issues and/or barriers to implementation (personnel, training, layout, system, process, etc.). What can be done to overcome these issues?

Note: Process maps count as 1 page each (These can be hand drawn, but must be professional looking)