# AC 2010-57: IMMERSIVE LEARNING USING LEAN SIX SIGMA METHODOLOGY IN THE MANUFACTURING ENGINEERING TECHNOLOGY CAPSTONE COURSE

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# Immersive Learning using Lean Six Sigma Methodology in the Manufacturing Engineering Technology Capstone Course


## Abstract

This paper will discuss how Lean Six Sigma immersive learning projects were used to satisfy requirements for Manufacturing Engineering Technology (MfgET) capstone experiences and Lean Six Sigma Black Belt certification projects; as well as satisfying an important component of Ball State University's strategic plan. The three driving components will be summarized and a history of how Lean Six Sigma projects became the core which links the three driving components will be provided. Seven Lean Six Sigma projects (four of which also served as MfgET capstone projects) performed in the first cycle for the Minor in Process Improvement (2009) will be briefly described.


## The Driving Components

Lean Six Sigma immersive learning projects immerged as the core which was used to satisfy the requirements of three driving components:

1. B.S. Manufacturing Engineering Technology Capstone Project as required by TAC/ABET Criteria.
2. Minor in Process Improvement which provides students Lean Six Sigma Black Belt training and requires students to complete a commercial project if they desire professional certification.
3. Ball State University's Strategic Plan which emphasizes the importance and stipulates specific criteria which defines immersive learning.

These components are depicted graphically in Figure 1 Lean Six Sigma Immersive Learning Project Core of Driving Forces.

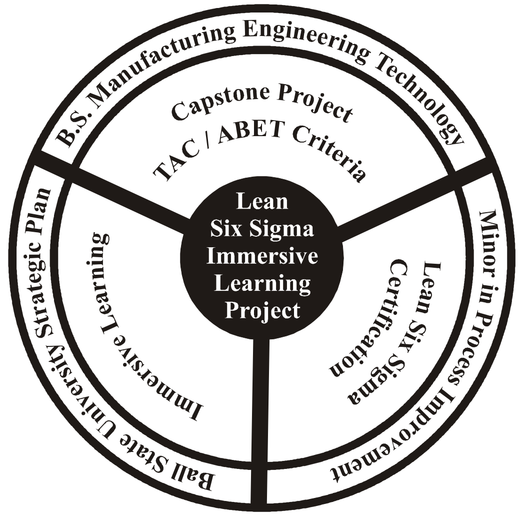


**Figure 1 Lean Six Sigma Immersive Learning Project Core of Driving Forces**

The B.S. Manufacturing Engineering Technology (MfgET) at Ball State University requires students to complete a two semester capstone experience as does Ball State's Minor in Process Improvement (MIPI), which is focuses on providing undergraduate students Lean Six Sigma Black Belt training and the opportunity to earn certification. These two programs share two courses: ITMFG 265 – Statistical Quality Control and ITMFG 425 – Design of Experiments. MfgET students expressed an interest in the MIPI and a decision was made to allow students who were enrolled in both programs to satisfy both the requirements of the two semester MfgET capstone experience and two semester project requirement for the MIPI with a single Lean Six Sigma project as long as it satisfied the criteria of both programs. This meant that students enrolled in the MfgET program would only need two additional courses: ITMFG 104 – Introduction to Six Sigma and ITMFG 375 – Advanced Six Sigma in order to complete the MIPI.

TAC/ABET Criteria requirements with regard to the capstone experience as stipulated in the 2009-2010 Criteria for Accrediting Engineering Technology Programs is brief but explicit. The criteria states under Criterion 5, Curriculum, Technical Content: "The technical content of a program must focus on the applied aspects of science and engineering…" and "must develop the skills, knowledge, methods, procedures, and techniques associated with the technical discipline and appropriate to the goals of the program." Part d stipulates, the "Capstone or other integrating experiences must draw together diverse elements of the curriculum and develop student competence in focusing both technical and non-technical skills in solving problems.[1]"

Criterion 3 of the General TAC/ABET criteria provides for the following desired outcomes:

a. Demonstrate mastery of knowledge, techniques, skills and tools of the discipline
b. Apply current knowledge to emerging applications
c. Design and conduct experiments and analyze and interpret experimental data
d. Creatively design systems, components, and processes
e. Function effectively on teams
f. Identify, analyze, and solve technical problems
g. Communicate effectively
h. Recognize the need for and engage in life long learning
i. Understand professional and ethical responsibilities
j. Understand the impact of solutions in a professional, societal and global context
k. Exhibit commitment to quality, timeliness, and continuous improvement

This general criteria also serves well as criteria for evaluating the capstone experience.

Lean Six Sigma Certification varies widely and there is no official certifying body. Historically, certification has been controlled by the consulting industry and more recently by professional associations and individual organization criteria. The paper *"Six Sigma: Does it belong in the Manufacturing Curriculum?"* discusses this issue in more detail.[2] Dr. Mikel J. Harry, (http://www.mikeljharry.com) the Co-creator of Six Sigma and the world's foremost expert on Six Sigma, is a graduate of Ball State University's Department of Technology. Dr. Harry donated his Mindpro™ Lean Six Sigma Training Software to Ball State University[3] and worked with the University to develop Ball State's Minor in Process Improvement and criteria for Lean

Six Sigma Certification[2]:

- Students who complete the Minor in Process Improvement – a four course sequence covering Lean Six Sigma body of knowledge and a fifth course requiring completion of a simulated project – and who pass the commercial certification exams receive a Lean Six Sigma Black Belt Certificate of Proficiency from Ball State University which is signed by Dr. Mikel Harry and the coordinating faculty member (must hold Lean Six Sigma Black Belt Certification).

- Students, who also complete a commercial project at a professional level as judged by instructing faculty, the community partner, and a committee from the Lean Six Sigma advisory board, may also be granted a Lean Six Sigma Black Belt (LSSBB) Professional Certification issued by Ball State University. Note: in the first cycle (2009), granting of the LSSBB Professional Certification was at the discretion of the advising faculty member as criteria for formal evaluation by outside parties was not in place.

In the first two cycles (2009/2010) of the Minor in Process Improvement, all students were required to complete a commercial project. However, after reviewing the results of projects from the first cycle, this requirement was changed by reducing the MIPI from 18 hours to 15 hours and making the project optional. The MIPI advisory board believed that while the projects were a significant learning experience, not all students were prepared to accept the responsibilities and time commitments required of a professional level project that was not directly associated with their major.

Students, who elect to do a project for the MIPI, will be required to take two additional project classes resulting in a 21 hour minor. MfgET students who want to combine their capstone experience with the LSSBB commercial project must elect to take the 21 hour minor which will require an additional three classes above their major as opposed to an additional two classes required in the first two cycles of the MIPI. Students who want to use a single project to satisfy the requirements of both the MfgET two course capstone experience and the two course LSSBB project must select a project that is manufacturing oriented and "demonstrate mastery of knowledge, techniques, skills and tools of the discipline" as outlined in TAC/ABET general criteria and must perform the project using the Lean Six Sigma DMAIC (Define-Measure-Analyze-Improve-Control) framework. Projects requiring the use of Design of Experiments and statistical analysis using a variety of commercial software packages are preferred. Note: students do not receive dual credit for completing the single project; they simply receive dual use of the credit – the 6 hours of credit earned for the project is used to satisfy the 6 hour project requirements of each program.

Ball State University's commitment to immersive learning, which is part of the University's strategic plan, serves as a driving force for including projects as part of the MIPI. Immersive learning experiences at Ball State must have most or all of the following characteristics:[4]

- Carry academic credit
- Engage participants in an active learning process that is student-driven, but guided by a faculty mentor

- Produce a tangible outcome or product, such as a business plan, policy recommendation, book, play, or DVD
- Involve a team of students, often working on a project that is interdisciplinary in nature
- Include a community partner(s) and create an impact on the larger community as well as on the student participants
- Focus on student learning outcomes
- Help students define a career path or make connections to a profession or industry

Ball State University President JoAnn Gora feels very strongly about immersive learning: "In these experiences, the students drive the learning process and play a critical role in defining the end product. It is "active learning" at its best, and the experiences connect students to the industries in which they want to establish their careers." "We are redefining education by creating … an immersive learning environment that allows students to engage with learning in a new way: intense, creative, collaborative, personal, and, at times, even in ways that mirror the risk and reward of real-life ventures. We believe this is an essential way to help shape our students for leadership in the 21st century and to orient education toward the needs of knowledge economics in the future." [5]

The Lean Six Sigma Black Belt projects that serve as the capstone experience for the MfgET program and project requirement of the LSSBB certification do not meet Ball State's immersive learning criteria of "Involve a team of students, often working on a project that is interdisciplinary in nature." This emphasis on teams is consistent with TAC/ABET's general criteria of "Function effectively on teams." Lean Six Sigma certification requires that projects be completed individually; therefore, doing the project with a "team of students" does not work. However, the use of multidisciplinary teams is a critical component of any Lean Six Sigma project, so students do meet the spirit of the immersive learning criteria and the TAC/ABET criteria, in that they will be working with a multidisciplinary team of working professionals.

Lean Six Sigma Black Belt projects satisfy the requirements of all three driving forces and provide MfgET students an opportunity to differentiate themselves by simultaneously completing a Lean Six Sigma Black Belt project with their capstone experience. Even students who do not earn a "professional certification," because their project is not completed at a "professional" level, will have experienced the opportunity to perform a real world project with the expectation of producing at a professional level and should be better prepared to perform their next project, which will occur as a full time employee.

**Community Partners and Collaboration Models**

Real world projects require participation by community partners. If the projects are going to be Lean Six Sigma based, then it is also necessary for the community partner to either have a Lean Six Sigma culture or be willing to adopt the culture for use with the immersive learning project. This additional restriction makes the task of finding and establishing a relationship with community partners even more difficult than normal.

Industrial projects had been utilized for the MfgET capstone experiences in the past using a model that required students to find their own community partner. While students who listened closely to their peers realized this would be a requirement, they were not made aware of this requirement formally until the start of the sixteen week semester in which they enrolled for the capstone experience. The issue of obtaining a community partner and completing a project in sixteen weeks was compounded by the fact that most students did not have manufacturing contacts and were taking a full load of courses. The result was a high number of "Incomplete" grades being issued. This was the driving force for making the capstone experience a two semester requirement. Even with a two semester sequence, a great deal of calendar time is lost if a community partner is not sought until the start of the course. In the case of both the MfgET program and the MIPI improvement, students who are candidates for the immersive learning project are easily identified through the prerequisite structure. Therefore, a proactive approach of finding community partners prior to the start of the class is used.

A decision must be made with regard to whether the student or the faculty member who will be supporting the projects will take the lead in identifying and establishing the relationship necessary for collaboration. There are risks associated with both sides of this decision; but are beyond the scope of this paper. Because the MIPI was a new program and the projects had the special requirement of a Lean Six Sigma culture or the willingness to use the Lean Six Sigma methodology, the faculty member took the lead role in finding and establishing collaboration opportunities with community partners for the first two cycles. Even if the burden were placed upon the students to find their own community partners, the faculty member would still have to be involved to mitigate risks to the university. Regardless of the path chosen, the time necessary for this task should not be underestimated both in terms of number of hours and the calendar lead time required.

The following collaboration models were used in the first cycle of Lean Six Sigma immersive learning projects:

- Community Partner has Lean Six Sigma culture**.** An on staff LSSBB serves as LSSBB Mentor and the course instructor serves as Academic Advisor. This is the desired model; however, the number of community partners available was limited, so other models had to be adopted.

- Community Partner does not have a Lean Six Sigma culture but is willing to support a project using the Lean Six Sigma methodology.

    - Third party volunteer serves a LSSBB Mentor and the course instructor serves as Academic Advisor.

    - Course instructor serves as both the LSSBB Mentor and Academic Advisor. This places a significantly higher burden on the course instructor; however, was necessary due to the lack of available community partners with a Lean Six Sigma culture who were willing to support projects and LSSBB volunteers who met demographic requirements.

**Roles and Responsibilities**

There are three partners in the Lean Six Sigma immersive learning collaboration:

- The University
- The Community Partner
- The Student

If a third party LSSBB Mentor is required, then they become a fourth partner who must be considered. Each of these partners has needs and associated risks which must be considered and mitigated. Some of the needs and risks are obvious; but, there are others that are not so obvious. As stated previously, the discussion of risk is beyond the scope of this paper but will be considered for future publication. The project roles are:

- Academic Advisor
- Project Champion
- Process Owner
- Lean Six Sigma Black Belt Mentor
- Student

## Academic Advisor

As discussed previously, the Academic Advisor may assume the role of finding community partners and matching those partners to students. Even if the Academic Advisor delegates this task to the student, the faculty member still must serve in a consultant role to ensure that the community partner understands their role and the framework for collaboration and any risk to the University is mitigated.

The faculty member teaching the first class of the two classes associated with the Lean Six Sigma project, in the MIPI, has several obligations not directly associated with the project (Some of these responsibilities will be alleviated through the decision to make the project optional for the MIPI and by the additional class for those students electing the project option.). These obligations are handled in weekly lectures (approximately 3 hours per week):

- Supervision of Lean Six Sigma Black Belt Certification Exams
- Lectures on the collaboration framework, project scheduling, and other competency gaps which are perceived to be student weaknesses.
- Leading students through an extensive Lean Six Sigma simulation project which is designed to reinforce the complexity level associated with a LSSBB project and enhance the students' analytical skills and skills in utilizing statistical software.

Directly related to the project, the Academic Advisor must review weekly progress reports from the student and evaluate whether or not the student is meeting their obligations with respect to the project. These weekly reviews can be face to face with the student, by email, or by video conference as necessary. Face to face meetings are recommended initially; however, they are time consuming on both the part of the Academic Advisor and the student. If the student is on track and appears to be able to work with a lower level of supervision, alternative methods are appropriate. The Academic Advisor must also help the student resolve any competency gaps which might occur.

A role of the Academic Advisor that might not be so obvious is the need to train the Project Champion and LSSBB Mentor. As Yost indicates, this by itself is a challenge since they are not educators. They tend to focus on deficiencies rather than focusing on both strengths and weaknesses. [6] Therefore the Academic Mentor must take on the additional role of educating the Project Champion and LSSBB in the role of being an educator. Beyond the issue of key role players not being educators, this is typically a new experience for them and no matter how clearly the roles are outlined, diversity in personalities and management styles, and the fact that the student and Academic Advisor are not "part of the organization" are likely to result in project supervision gaps. The burden to recognize and compensate for these gaps falls on the Academic Advisor.

The Academic Advisor must also provide risk mitigation and serve in the role of mediator. All parties do not always meet their commitments. Community partners and LSSBB Mentors may agree to support a project and then lose resolve due to internal issues, economic commitments, time constraints, frustration with student commitment or the process, or any myriad of other reasons. A student may have conflicts with course load; the inability to adapt to being in a position of leading a project and setting not only their own deadlines but those of their team; a student who is being paid, may sandbag a project for reasons of income; and again a myriad of other reasons. The Academic Advisor must be on guard for all such issues and then mediate the issues, as any of them might result in project completion delays or failure. Failure, regardless of cause, reflects negatively on the university, the program, and the collaboration process. This is true whether the Academic Advisor established the relationship with the community partner or delegated the responsibility of obtaining a community partner to the student. If the Academic Advisor does not take this role seriously and serve in a proactive role, there is a high risk for embarrassment at minimum and possible legal consequences at worst.

The Academic Advisor is responsible for guiding students in preparation of a final report. Most community partners will not view a formal final report as a critical, or even necessary, element of the experience; but, it is an important academic element and is of benefit for the student to document their experience.
The Academic Advisor is accountable for assessment and assignment of a grade; but shall rely heavily on input from the LSSBB Mentor and community partner.

## Project Champion

The Project Champion typically holds a senior management position with the community partner and is usually, but not always, the primary connection between the university and community partner. The Project Champion is responsible for project selection in consultation with the Academic Advisor. The Project Champion is responsible for providing the necessary resources and breaking down barriers within the organization. The Project Champion should hold periodic project reviews to assure that the project is progressing as planned and that the result will produce a result that resembles (and aligns with) the needs of the organization as conceived when the project was initiated – soon after project initiation, these needs will be summarized in a

Lean Six Sigma Project Charter. Project Champions must constantly guard against intruding into the process and offering solutions and let the Lean Six Sigma process develop those solutions.[7]

## Process Owner

The Process Owner is an employee of the community partner and has direct accountability of the key process related to the project. This is the person who is most familiar with the process and can be considered the technical expert. While students are matched to community partners as closely as possible based upon their academic major, they may or may not have technical knowledge regarding the process. The student serves as the "process improvement specialist with an outside eye" and not the technical expert. For community partners who do not have a Lean Six Sigma culture, this is often in conflict with their expectations and can be a major hurdle. It is less of an issue with community partners that have a Lean Six Sigma culture as many of these organizations recognize that it is common for the LSSBB to not have technical expertise with regard to the process and in fact some organization prefer LSSBB's who are not familiar with the process so that they do not bring a bias to the project. The Process Owner will guide the student in selecting and ensuring active participation of the project team.

The immersive learning Lean Six Sigma project will terminate at the Control Plan. There typically is not sufficient calendar time available for the student to implement the Control Plan; therefore, this becomes the responsibility of the Process Owner.

## Lean Six Sigma Black Belt Mentor

As discussed previously, the LSSBB Mentor may be associated with the community partner (this is the desired collaboration model), a third party volunteer, or a dual role assumed by the Academic Advisor.

While students have studied the Lean Six Sigma body of knowledge extensively, most have never participated in, let alone led, a major project. Application of the tools which have been attached to their tool belt can be a significant challenge. Students often struggle with even knowing where to start, so development of "phase level" plans and approval of those plans before implementation is critical to not wasting valuable resources and causing unnecessary frustration by all parties. To develop these plans, students are instructed to list the tools they believe are appropriate for each phase; organize the tools in chronological order; and estimate the time and resources needed to implement each tool. Once students have assimilated this information, they meet with their LSSBB Mentor who will provide feedback and critique which will allow the student to develop a formal "phase level" plan.

The meeting between the LSSBB Mentor and the student when they review the student's Define Phase plan proposal is critical. It is at this meeting where roles of the LSSBB Mentor and student are confirmed. The author does not recommend participation by the Academic Mentor at this meeting; however, a follow-up interview of both the student and the LSSBB mentor prior to implementation of the plan is recommended. If there is a misunderstanding of roles and responsibilities or a differences with respect to expected competency levels it is likely to surface in this meeting. Too few projects have been completed at this point to make a final determination; but, it may be that a follow-up meeting, after the Define Phase proposal and before implementation, involving the LSSBB Mentor, student, and Academic Advisor should be a project requirement.

It was noted above that the Project Champion must constantly guard against offering solutions; likewise; the LSSBB Mentor must constantly guard against assuming the role of project leader. However, they must also understand that in the role of mentor of an undergraduate student involved in their first project, they are an educator. Failure to balance these roles in the define phase proposal meeting is critical – too little help and the student will become frustrated and too much help and the student will become dependent.

It is not the role of the LSSBB Mentor to fill competency gaps. The student was extensively trained in the Lean Six Sigma body of knowledge and if there is a competency gap, the responsibility to fill that gap falls to the student and Academic Advisor. However, the LSSBB Mentor is responsible for advising the Academic Advisor when they perceive a competency gap. This can be an issue as the LSSBB Mentor may have aligned themselves with the student and does not want to be the “rat” that tells on the student. However, failure to assume this critical role may result in increased dependency by the student on the LSSBB mentor or the loss of opportunity to improve the body of knowledge provided to the student in the core classes.

One area where the LSSBB Mentor can provide a leading role is by assisting the student in establishing estimates of the time required to complete each task. The student will use these estimates to establish project milestones. Students typically do not have sufficient experience to make even a good guess, so they may simply discount the value of establishing milestones. The LSSBB Mentor must take care to consider the inexperience of the student when assisting with estimates, but the estimates will be much more realistic than a guess by the student and will enhance the requirement of providing milestones.

The LSSBB Mentor shall query the student to ensure they are prepared for and shall attend all Phase Gate Reviews

The LSSBB Mentor serves as the eyes and ears of the Lean Six Sigma Academic Advisor and should not hesitate to admonish and correct the student; or to communicate issues with regard to attitude, ethics, work deficiency, academic competency, or any unsatisfactory performance by the student to the Academic Advisor. The LSSBB may feel more comfortable in dealing with student issues by simply providing excessive participation (failure affects the LSSBB mentors reputation too) which may result in successful completion; but, a negative feeling regarding the overall experience.

The LSSBB mentor shall assist the student in the event the community partner Project Champion or Process Owner becomes non-cooperative with regard to following the Lean Six Sigma methodology and shall be responsible for communicating with the Academic Advisor with regard to the potential for project failure.

## The Student

While the Academic Advisor may be proactive in finding and establishing a relationship with a community partner, this is the accountability of the student. Regardless of who establishes the community partner, the collaboration must be approved by the Academic Advisor.

The Student is the Lean Six Sigma Black Belt candidate and has overall project management responsibilities. Students often view support, whether it from the LSSBB Mentor, Academic Advisor or others as a transfer of responsibilities. The Academic Advisor must be on guard regarding this issue and at the first sign, remind students that they are the project leader.

Having a Project Champion who is providing broad oversight; a Process Owner who provides technical issues and handles logistical issues; a LSSBB Mentor who provided guidance and critique; and an Academic Advisor who provides academic oversight and final assessment in the form of the grade, is a form of matrix management – the student has lots of bosses. Many people struggle in a matrix management setting and this will be a struggle for most students. It is important for the student to make sure they keep all participants in the loop, without annoying them with inappropriate details. The Academic Advisor will once again have to be on guard for this issue and guide the student on the level of communication that is necessary. Students who may be accustomed to attending a three hour lecture and not taking any notes is likely to be shocked that they must document phone conversations, interviews, and provide meeting minutes. The required weekly status reports will alleviate some of these issues.

Lastly and most importantly, the student is accountable for project success and maintaining a positive relationship with the community partner and Black Belt Mentor.

### Project Selection and Assignment of Students

Organizations often want to give back to the community; potential project sponsors may want to give back to their alma mater; or there may be a need to provide an opportunity for a student who is somehow connected to an organization. These are inappropriate reasons for participation. Project participation offered for purely philanthropic purposes have a high risk of failure. The project must address a need within the community partner's organization. When meeting with potential community partners, the following statement is effective in guiding the community partner in selecting a project: *The perfect project is one that links to the organization's strategic plan and when reviewing assignment of resources to projects, is just below the cut. The next time allocation of resources is made the project once again is just below the cut.* This type of project is important to the organization; but, not so important that it must be completed on a high priority basis. This type of project has a high opportunity for full implementation and the parties involved will likely recognize its importance. Because it is not time critical, the student will not be pressured to compromise the Lean Six Sigma process.

The community partner must be willing to implement the solution. Hypothetical projects have value; but, the idea of an immersive learning project is to realize value for the community partner. Hypothetical projects could be simulated in a classroom with much less effort.

The first project course is scheduled in the Spring semester when students typically carry a full load of courses. Students are required to commit 12 hours of their time per week based upon a 15 week semester (students are excluded from a commitment during finals week). The twelve hours are budgeted as follows:

- Class Lectures, Certification Exams, and Academic Advisor meeting (4 Hours)
- Certification Exam Study (2 Hours)
- Weekly Status Report (1 Hour)
- Direct Immersive Learning Project Time (5 Hours)

This means the student will commit approximately 75 hours directly to the immersive learning project during the 15 week semester. Travel time to and from the community partner are above and beyond the 12 hour per week commitment. Students are allowed to flex their time if prearranged with their community partner but will not be allowed to accumulate a significant deficit. This is a real world project so the student is required to spend time onsite at the community partner's location. However, time spent doing analytical work, research, or other work offsite counts as direct immersive learning project time as long as the time is appropriately documented. Students are required to account for this time in their weekly submittal. Students have been known to exaggerate their time logs and it is incumbent upon the Academic Advisor to keep them honest through careful observation and query.

The second project course runs the full summer term. Students are required to commit 40 hours per week until the project is completed. Students who have summer school requirements or other summer commitments may be accommodated if agreeable to all parties. Students are enrolled in the first summer term (5 weeks) and given an incomplete if the project is not completed. The project is expected to be complete by the end of the second summer term (an additional 5 weeks). Based upon this schedule an appropriate project would require a 275 to 475 hour time commitment from the student, including the final project report.

Yost notes that attempting to balance the workload for the students so they do not become completely overwhelmed can be an unforgiving process. Having the project divided into phases, with associated deadlines, helps keep the student diligent and on task. Unfortunately the necessary decomposition does not necessarily coincide with a real world work breakdown structure.[Error! Bookmark not defined.] Use of the DMAIC methodology, requiring phase plans with milestone commitments, and having formal DMAIC toll gates provides a structure, when combined with weekly project submittals, that smoothes out the process and alleviates "cram mode" found on many undergraduate projects.

**First Cycle Projects**

Seven students participated in the Minor in Process Improvement's first cycle of projects. Four of the seven students were Manufacturing Engineering Technology majors. The projects will be described generally. Organization names, student names, and proprietary details are omitted for confidentially and proprietary reasons.

- Project #1: Lathe Productivity Improvement, Fortune 500 Manufacturer
- Project #2: Injection Molding Cycle Time Reduction, International (Ping Hu, China) Manufacturer
- Project #3: Packaging Design Improvement, International (Ping Hu, China) Manufacturer
- Project #4: Design for Manufacturability Training, International (Ping Hu, China) Manufacturer
- Project #5: Product Engineering Cycle Time Improvement, International (Ping Hu, China) Manufacturer
- Project #6: Reduction of Response Time to High Weeds and Grass, City Government
- Project #7: Reduction of Time to Handle Non-Account Transactions, Large Implement Dealer

**Project #1**
**Lathe Productivity Improvement, Domestic Fortune 500 Manufacturer**

This project was completed by a MfgET major. The project was completed with the preferred collaboration structure where the community partner had a Lean Six Sigma culture and an on staff LSSBB Mentor. The project required the use of the classical Lean Six Sigma tools and was implemented through a Kaizen event. The project resulted in improvement with projected savings somewhat below a typical Lean Sigma Black Belt Project. Because the Academic Advisor was in China during the summer portion of the project, there was a heavy dependency on the LSSBB Mentor and the existing Lean Six Sigma culture. Communication was primarily between the student and Academic Advisor and student and LSSBB Mentor, with very little communication between the Academic Advisor and the LSSBB Mentor. Communication in the latter weeks of the project, were primarily through email. This project would be considered a success which can be contributed largely to the collaboration model and the assumption of responsibility by the LSSBB Mentor..

Projects #2 - #5 were completed in collaboration with a large Chinese toy manufacturer located in Ping Hu, China. The manufacturer did not have a Lean Six Sigma culture so the supervising faculty member served a dual role as Academic Advisor and LSSBB Mentor. A relationship was developed and project selection was accomplished through two preliminary visits by the supervising faculty member. Communication was accomplished by video conference and email for the first semester of the project. The faculty supervisor and students traveled to the manufacturer's Ping Hu, China facility for the ten week summer term (the student involved in Project #5 only spent five weeks in China).

**Project #2**
**Injection Molding Cycle Time Reduction, International (Ping Hu, China) Manufacturer**

This project was completed by a MfgET major. There was an indication by the manufacturer that their injection molding cycle times were higher than industry standard. However, this assumption was based solely on the statement of a former employee; therefore, this project required a benchmarking study as its first step. The benchmarking study indicated an opportunity for improvement. The project required use of classical Six Sigma tools with multi-disciplinary collaboration. Machine allocation was limited, so a true design of experiment could not be performed; however, extensive data was collected and analysis of variance was performed. Procedures were developed resulting in 29% cycle time reduction with no increase in defects. The organization was shown how to replicate such studies without significantly interrupting production. This project could be considered a success by all standards. As a side benefit, anomalies in the inspection process and standard operating procedures were also uncovered with recommendations for improvement provided to the community partner.

**Project #3**
**Packaging Design Improvement, International (Ping Hu, China) Manufacturer**

This project was performed by a MfgET major. Through multi-disciplinary collaboration the project was narrowed to simplifying packaging design by reducing the number of fasteners (wire ties and silicon bands) required. The manufacturer had begun implementation of package simplification by eliminating fasteners through the use of undercuts in a thermoformed pocket which trapped the product. However, a typical project required approximately ten design iterations. Group technology was utilized to classify product. It was discovered that simply by placing the product in a thermoformed pocket, three-degrees of freedom (two degrees of movement and one degree of rotation) were controlled. It was further discovered that the primary focus was restricting the other degree of movement – preventing the product from falling straight out of the package – when the real issue was rotation of the product about the designed undercuts. Essentially, the designers and thermoformer were not appropriately applying the theory of six-degrees of freedom. The project was not completed at the desired level due to logistic and personal issues encountered at a critical time. However, projected improvements consistent with a LSSBB project were reached even with a compromise in the project. Maybe the most significant aspect of the project was development of a pre-test which allowed the packaging design to be evaluated by the thermoformer, bypassing the significant number of iterations involving the community partners design team.

**Project #4**
**Design for Manufacturability Training, International (Ping Hu, China) Manufacturer**

This project was completed by a MfgET student in cooperation with a Chinese speaking faculty member. The community partner indicated that they were having variability issues attributable to "lack of basic engineering skills." Design for Manufacturability principles were researched and a survey instrument was developed. The survey was developed in both English (Hong Kong engineers speak English and Cantonese) and Mandarin (Mainland engineers speak Mandarin). Analysis of variance was performed and the critical deficiencies were identified. Training videos (in both English and Mandarin) were developed to address the critical deficiencies. Pre-test and post-test analysis to validate improvement is currently being completed. The community partner's Process Owner has indicated that the project will be effective.

**Project #5**
**Product Engineering Cycle Time Improvement,**
**International (Ping Hu, China) Manufacturer**

This student who completed this project was a Chemistry major, with a Minor in Industrial Technology. The student was selected for the China experience because the initial project was related to a paint adhesion issue which was more consistent with the students major; unfortunately this project was dropped by the community partner.

There is a very short cycle time from idea generation to production with many steps involved. Development of a process map for this project consumed most of the entire project time. With language barriers, the student had to gather information of how the process worked and then document it via a process map. This was done in the initial sixteen weeks of the project via email and video conference which are not ideal for a process with this complexity. Once onsite it was discovered that there were many errors in the process as originally mapped. It is very common for the actual process to not match the described process map; however, given the number of steps in this process making these corrections was extremely time consuming. Time only allowed the student to make broad recommendations with regard to improvement. Some might consider this project a failure or incomplete at best. In terms of a pure Lean Six Sigma project, incomplete might be an accurate description; however, the portion of the project which was completed was done at a high level and provided the community partner with a documented view of the process. Given the constraints, this project should be considered a success.

**Product #6**
**Reduction of Response Time to High Weeds and Grass, City Government**

The student completing this project was a Risk and Insurance major. The project was completely disassociated with her major. The city had completed a previous Lean Six Sigma project with cooperation of an outside LSSBB volunteer, and had recently hired a Lean Six Sigma Master Black Belt. However, the City was not steeped in a Lean Six Sigma culture. The LSSBB Mentor was a third party volunteer. The timing of the project was critical in terms of need, so a lot of parallel solutions outside the Lean Six Sigma methodology were being implemented simultaneously with the student's work which followed the Lean Six Sigma process. Another factor working against the project was that the Process Owner responsibilities were being shifted from one department to another. Like with Project #1, heavy reliance was placed on the LSSBB Mentor to supervise the project because the Academic Advisor was in China during the last several weeks of the project and the international projects were requiring a disproportionate amount of time. In the end, the project resulted in approximately a 60% reduction in response time. However, some of these improvements were the result of "quick-hits," ordinance changes, and other parallel solutions. The student was uncomfortable taking credit for improvements resulting from the Lean Six Sigma project. However, it was clear that the student was fighting cultural issues and a project which in hind-sight should have been rejected due to the need for quick implementation. The student followed the Lean Six Sigma process, improvements were achieved, and it was clear that the student had an impact on the culture. The project should be considered a success.

**Project #7**
**Reduction of Handling Non-Account Transactions, Large Implement Dealer**

This project involved an Operations Management major. The scope of the project was related to the student's major. The community partner was a large implement dealer whose business model was designed around contractors who had a company account. It was not uncommon for customers who did not have a company account to want to make a purchase of spare parts or clothing; but, when this occurred, the company's methodology for handling the transaction would take 15-30 minutes. This community partner had an extremely strong Lean Six Sigma culture and the LSSBB Mentor was on staff. This project had characteristics which indicated a high potential for success. Student communication with the Academic Advisor was poor; however, an onsite meeting at the conclusion of the first semester indicated that the community partner was satisfied with the students work. Unfortunately during the second semester communication from the student with both the community partner and Academic Advisor collapsed and the project was terminated. This is an example of the high risk and potential embarrassment to the university and program associated with such projects.

## Reflections and Lessons Learned

Many of the lessons learned are reflected in the project framework described in the body of this paper. However, it is clear that providing students the opportunity to do immersive learning projects such as the Lean Six Sigma projects described in this paper is expensive and risky.

- The university compensation and reward structure does not incentivize taking on such projects. The effort required by the Academic Advisor far exceeds the compensation and reward system when compared to a normal class.

- A significant commitment must be made by the student. The student is required to be the project leader. Almost all of the students had poor performance periods due to stress during the experience: some attributable to the demand of being in a project leader position; some in terms of balancing time with other courses; personal obligations; "senioritus;" and some attributable to breakdowns in support and conflict of expectations from the Academic Advisor and LSSBB Mentor.

- The commitment from the community partner and LSSBB Mentor is also significant. They must work the project into their regular business, while following an academic schedule driven by the student's availability and capability. Even with the projects deemed successful, the early parts of project when the students were only dedicating 5 hours per week directly to the project, were painfully frustrating for the community partner and LSSBB.

Two of the LSSBB Mentors also serve on the Minor in Process Improvement Advisory Board, as does the MIPI Coordinator who served as Academic Advisor for all projects and LSSBB Mentor for the Chinese. The Advisory Board did a post-project review. The consensus was that the students may not have completed the projects on par with a professional LSSBB candidate; but, that the students matured through the project and are likely to be far ahead of their peers with regard to project implementation on their first jobs.

The response from students was mixed. Some students were so frustrated with the pressure to succeed placed on them by the Academic Advisor that they no longer speak. Others recognized the experience as clearly setting them apart from their peers; and, some make a direct correlation of their project to obtaining and performance levels in their first jobs.

Nine students will be performing projects in the second cycle (Spring / Summer 2010). Two of these students are MfgET majors. Projects cover manufacturing, computer technology, marketing, operations management, and software systems.

Due to the expense of delivery and the desire to provide exceptional and not acceptable experiences, the project requirement for the Minor in Process Improvement has been dropped. Students will still have an option to do a LSSBB professional project; however, they must join with a community partner and compete for the opportunity to participate in a limited number of projects.

TAC/ABET criteria requires a capstone experience for the MfgET B.S. program. Students participating in this program who elect to also take the Minor in Process Improvement will complete their projects using the Lean Six Sigma methodology as outlined in this paper.

## Conclusion

The DMAIC methodology of Lean Six Sigma provides a framework with helps guide students through their projects. The DMAIC framework along with the tools and statistical analysis taught in the Lean Six Sigma body of knowledge complements Manufacturing Engineering Technology, whether it is integrated as part of the Manufacturing Engineering Technology program or offered as a supplement to the curriculum as Ball State University did with its Minor in Process Improvement. Ball State University's Immersive Learning criteria, specifically requiring delivery of a product (this is one of the keys which separates immersive learning from internships and other experiential learning models), correlates directly with the TAC/ABET outcomes and criteria for a capstone experience. The model described in this paper could be easily adapted to almost any program which requires a capstone experience.

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