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Using A Fun Six Sigma Project to Teach Quality Concepts, Tools, and Techniques

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Abstract

Research has shown that students learn better if they are engaged in, and motivated to struggle with, their own learning [5]. For this reason, if no other, students appear to learn better if they work cooperatively in small groups to solve problems. Furthermore, learning quality engineering concepts, such as variation, using traditional methods can be challenging for many college students with no prior background. It makes it even more challenging when methods such as statistical process control, process capability analysis, and design of experiments are involved.

This paper presents a Six Sigma project utilizing a catapult as a process with multiple controllable factors as input variables and the distance where a ball lands as the output (dependent variable). The aim is to minimize variation and attain a target distance. The Six Sigma improvement model: Define-Measure-Analyze-Improve-Control (DMAIC) was employed. Each member of the team assumed the role of a project leader for at least one of the DMAIC phases. In addition to applying quality tools manually, students also utilized a statistical software to analyze experimental data.

Results show that students were able to take an existing process and make significant improvements in terms of reducing variation and centering the process using the tools and techniques learned in class throughout the semester. In their presentations and feedback, teams commented on how this learning-by-doing experience has helped them see how such tools can be used together.

Introduction

Teaching statistics and applied statistical methods can be challenging for both educators and students. Students may not be ready for not having sufficient mathematical or statistical preparation [1]. As a result, it is not uncommon to have misconceptions about statistics, in addition to lack of interest. Many students have negative attitude or when it comes to learning statistics, besides the anxiety that comes with it [2]. As misconceptions and attitudes have been found to correlate with performance in statistics courses [3], changing them can be challenging for educators [4].

Research shows that students learn better if they are engaged in, and motivated to struggle with, their own learning. For this reason, if no other, students appear to learn better if they work cooperatively in small groups to solve problems [5]. Collaborative learning has been described in college level statistics courses in various forms [6-10]. Educators employing collaborative or cooperative learning methods reported greater student satisfaction with the learning experience [8, 9], reduction of anxiety [10, 11], and concluding that student performance was greater than individual students could have achieved working independently [6, 10]. Similar results were found in applied statistics courses where frequent and regular encounters of planned collaborative work appear to be effective in improving performance for undergraduate students [13].

The three essential elements for collaborative learning are: co-labor, intentional design, and meaningful learning [15]. That is, everyone on the team must be actively engaged (co-labor) in an activity or peer-led project designed to complement the course learning outcomes. As a result, this activity or project will increase student's knowledge and understanding of course content (meaningful learning).

Combining the collaborative learning with a Six Sigma project using a process improvement methodology like DMAIC can have many benefits. Six Sigma training using projects is more effective than traditional statistical courses and is even used in a master's level courses [16], [17]. Cudney and Kanigolla found that inclusion of a Lean Six Sigma project had a positive impact on students' learning of concepts included in the course [18, 19].

Another issue is the fact that the course includes many tools and techniques that are traditionally taught as individual topics. Linking these tools together using a quality improvement project methodology like Six Sigma demonstrates how they are used in a systematic way.

The Process

Learning-by-doing for a Six Sigma project requires availability of a process that needs improvement. Finding such a process in a college environment can be difficult, particularly with logistics, timing, etc., where a real project may take 3 to 6 months to complete. This becomes more challenging when multiple teams of students are involved and looking for such processes. Therefore, a process needs to be available to students throughout the semester to ensure the completion of all the project phases in a timely manner. Furthermore, one of the statistical techniques of interest is design of experiments (DOE). Applying this off-line method at an external organization only adds to the challenge.

With these requirements and limitations, it would be best to use a process simulator that can be readily available to students. Furthermore, it is important that the process simulator not be computer-based and requires physical cooperation among team members in making process adjustments to variables and measuring the response.

One of the best process simulators to satisfy the above requirements is the catapult. The catapult launches a small-sized ball (like table-tennis), based on a given setup. Therefore, the response (dependent variable) is the travelled distance when the ball first touches the floor (sometimes called in-flight distance). This in-flight distance can be affected by many controllable factors. However, for this project we used the following factors:

A. Tension setting - fixed arm
B. Tension setting - moving arm

C. Ball seat
D. Elevation
E. Ball Type
F. Hight of catapult placement
G. Reclining distance before release

The in-flight distance is measured using a tape measure to the closest inch. This is done visually by an inspector. As a result, the determined distance will also include variation from the measurement system, mainly the inspector.

Project Details

This project is an element of a required Quality Improvement course taught at a major Midwestern public university. Below are some of the learning outcomes of this course that relate to the Six Sigma project:

- Apply knowledge of engineering and statistical fundamentals to solve technical problems
- Understand the concept of variation and statistical quality control
- Understand how a company can address continuous improvement programs using Six Sigma or the seven-step A3 process
- Select and use the appropriate quality control or management and planning tool
- Work in a team environment to complete a project using applicable tools identified in in this course and report results in written and presentation formats

This project follows the Six Sigma *DMAIC* methodology, where the catapult is used as a process. The "product" is the horizontal traveled (in-flight) distance between the catapult itself and the point where the ball first hits the ground. The measurement is visually taken by an inspector using a measuring tape. The actual specifications (customer needs) are to *hit the target value consistently with minimal variation*. The students work in teams of four or five each.

For each phase (milestone) of the project, there is a list of deliverables that each team must produce by a due date. One of the deliverables in the *Define* phase is the project schedule or Gantt chart. This chart is used as a tool for outlining steps that need to be taken to complete each phase along with due dates and responsibilities. Table 1 lists minimum deliverables for each phase.

Table 1: Deliverables for A Six Sigma Project

Phase / Details	Deliverables
Define • Statement of the problem • Voice of the customer • Team members • Project Goals / Objectives	• Project Charter • SIPOC • Gantt Chart
Measure • Investigate measurement system: paired t-test for or Gage Repeatability & Reproducibility • Initial Control Chart (25 samples; sample size of 5) • Initial Process Capability Analysis (Specs to be given)	• Measurement System Analysis (MSA) (statistical analysis software) • Control Chart (both manually and using Statistical analysis software) • Process Capability Analysis (Statistical analysis software)
Analyze • Conduct root cause analysis • Conduct a designed experiment	• Ishikawa (fishbone) Diagram • 5 Whys • Designed experiments - minimum of 3 factors (statistical analysis software)
Improve • Actions to reduce variation (improve the process) • Measure stability and performance of improved process	• Actions taken to improve process • Control chart after improvement (Statistical analysis software only) • Capability Analysis after improvement (Statistical analysis software only)
Control • Establish a control plan / instructions for users • Recommendations	• Control Plan / Instructions for users • SPC Control Chart (Template with limits for use in confirmation run)
Confirmation Run • In presence of champion (instructor), run the improved process and	• Achieved objective (minimize variation) • Achieve objective (hit target)

In addition to the Gantt chart, the project *Charter* must also be completed in the *Define* phase. The charter includes, at minimum, the following information:

- Identification items: Team name, process owner, champion, organization, milestones, and team members
- Initial process capability: This is not determined until the *Measure* phase is complete
- Problem statement: This statement must be formulated by the team and will be the customer's perception.
- Goals and objective: The objective is to reduce variation and achieve target distance requested by the customer
- Scope: The team cannot invest in new equipment or make any design modifications to the process (catapult). They must use the process with its existing supplies (e.g., balls, rubber band, measuring system, etc.). Other restrictions include the physical area where experiments are conducted.
- Expected benefits: This includes benefits to the customer / user of the process.

Six Sigma Project Results

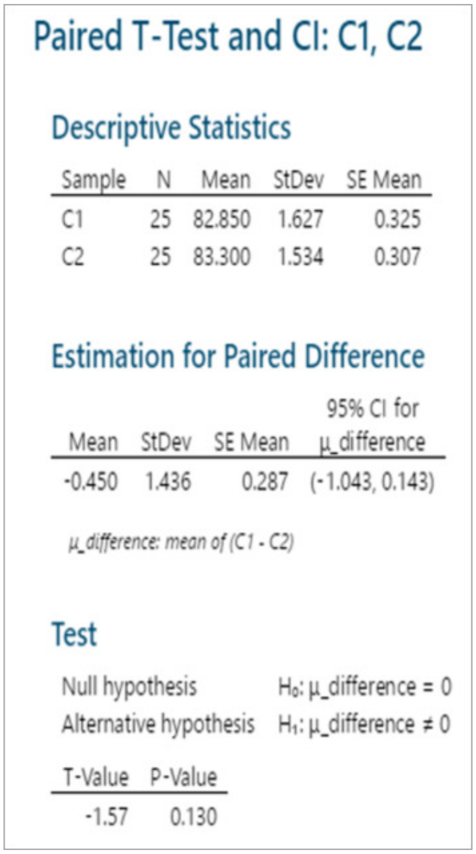
In this section, the results of the project will be presented as reported by one of the teams. The milestones for the project are the DMAIC phases themselves where deliverables listed in Table 1 are expected.

1. ***Define***: This phase is where the process is defined and scoped. It has three deliverables (at minimum) as follows:
    a. Project Charter: This includes information on the customer, leadership, due dates for each phase, problem statement, objectives and goals, expected benefits, among others. It should be mentioned that for this project, each student had a team leader role at least for one phase. The main goal of the project was to decrease variation by 50% and to hit a target of a certain distance.
    b. Supplier-Input-Process-Output-Customer (SIPOC) Map: The objective of this high-level map is to identify all relevant elements in the process. It helps scope the project from the supplier end all the way to the customer. In this project, the process steps included, set up and place ball, launch, measure distance, and record it.
    c. Gantt Chart: Students prepared a Gantt chart with the DMAIC phases as milestones and individual steps within each phase.
2. ***Measure****:* This phase is typically concerned with current conditions of a process which gives the team a baseline for improvements in later phases. To be specific, the concept of variation, including its two types of common and special causes, was emphasized here. At minimum, the following deliverables were expected in this phase:
    a. Measurement System Analysis: Since more than one student was going to be involved in measuring the distance, it is important to minimize the error introduced by the measurement system. Traditionally, gage repeatability and reproducibility (GR&R) study is used for continuous measures or attribute agreement analysis for discrete data. The repeatability part is concerned with the variation coming from the

instrument or gage while the reproducibility portion is concerned with the inspector. Since the inspector is the more likely source of measurement variation given that the tape measure is not manipulated, it was decided to use a statistical (paired-t) test as another alternative for the measurement system study. To do this, two operators (team members), will report distances of n samples. For each sample, the difference between the two distances, or d_i, is reported. The measurement system would be adequate if the average paired differences is not significantly different from zero. The test of hypothesis can be set up as follows:

$$H_0: \bar{d} = 0$$
$$H_A: \bar{d} \neq 0$$

The hypothesis testing was performed using α = 0.05 level of significance. If there is a significant difference, corrective action would be taken to bring the readings closer verified by running the test again. About half of the teams reported issues initially then resolved by creating a standardized way of reading the measured distances. Figure 1 displays the results of the paired t-test for one of the teams.



Paired T-Test and CI: C1, C2

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
C1	25	82.850	1.627	0.325
C2	25	83.300	1.534	0.307

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-0.450	1.436	0.287	(-1.043, 0.143)

μ_difference: mean of (C1 - C2)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference ≠ 0

T-Value	P-Value
-1.57	0.130

Figure 1: Paired t-test for Inspectors

The paired t-test in Figure 1 shows no significant difference between the inspectors. This can be concluded from the p-value of 0.13 or the 95% confidence interval which includes zero. This means that team members may rotate in taking measurements without influencing the measured distance by either reading consistently high or low. With this validation of the measurement system, the team can start taking samples for current conditions.

b. SPC Chart: Once the measurement system is deemed adequate, a variable control (X-bar and R) chart was used to study variation and the stability of the process. Each team member took five catapult launches in a row to make a sample while another located where the ball landed (inspector) and read the measurement to a third student (recorder) who manually entered the numbers onto a control chart template. This rotation took place until 25 samples were generated (Figure 2). Each team can only generate 5 samples (subgroups) at a time to simulate shifts so data collection was completed over a period of at least five days. This data was used as baseline for improvement.

c. The team determined the average and the range for each sample and plotted them on the chart manually during sampling and by using the software later. After about 25 different samples, the centerline and control limits were determined and graphed on the control chart. Control chart rules were followed, and actions were taken as needed [20].

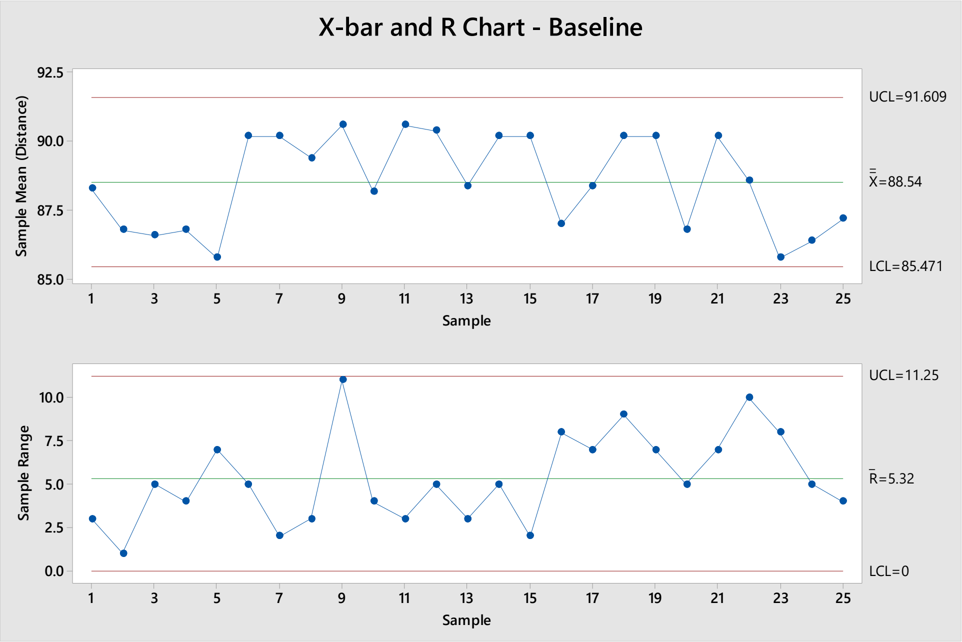
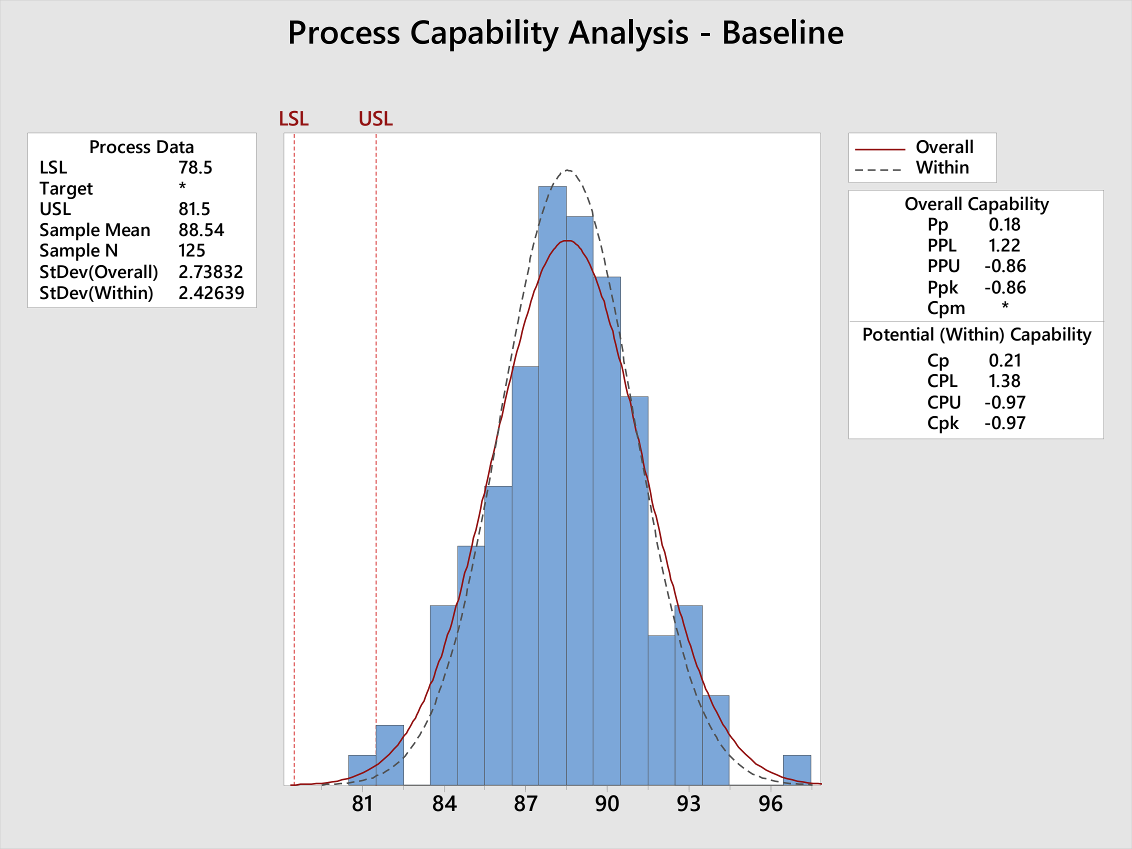


Figure 2: Baseline Process for Distance in Inches

d. Process Capability Analysis: Once process stability was established, the data collected was then used to run a capability study using a statistical software. Teams used specifications provided to compute capability indices Cp and Cpk. Generally, a target value +/- 1.5 inches were used to run and interpret the analysis. Figure 3 shows the process was not capable nor potentially capable when compared to specifications of 80.0 ± 1.5 inches, as reflected by the capability indices Cp and Cpk values. It exhibits too much variation when compared to the tolerance of (3.0 inches) and is also off-target.



Process Data	
LSL	78.5
Target	*
USL	81.5
Sample Mean	88.54
Sample N	125
StDev(Overall)	2.73832
StDev(Within)	2.42639

Overall Capability	
Pp	0.18
PPL	1.22
PPU	-0.86
Ppk	-0.86
Cpm	*

Potential (Within) Capability	
Cp	0.21
CPL	1.38
CPU	-0.97
Cpk	-0.97

Figure 3: Capability Analysis of Current Conditions

3. ***Analyze****:* In this phase, analysis to identify root causes of excess variation in the distance was conducted. At minimum, the following deliverables were expected from each team during this phase:
    a. Ishikawa (fishbone) diagram: Each team went through a brainstorming session to identify potential causes that could contribute to the inconsistency in the distance and excess variation. These potential causes were then placed under the appropriate categories (i.e. People, Equipment, Material, Environment, and Methods). It was emphasized to look for direct causes only at this point– not solutions and not indirect or root causes (Figure 4).
    b. 5-Whys: After completing the Ishikawa diagram, each team picked their top three to five causes and used the 5-Whys method to drill down to the potential root cause(s). From the Ishikawa diagram, the team identified three direct causes that could be contributing to the inconsistency in the distance. Using the 5-whys, the root causes were identified (Table 2).

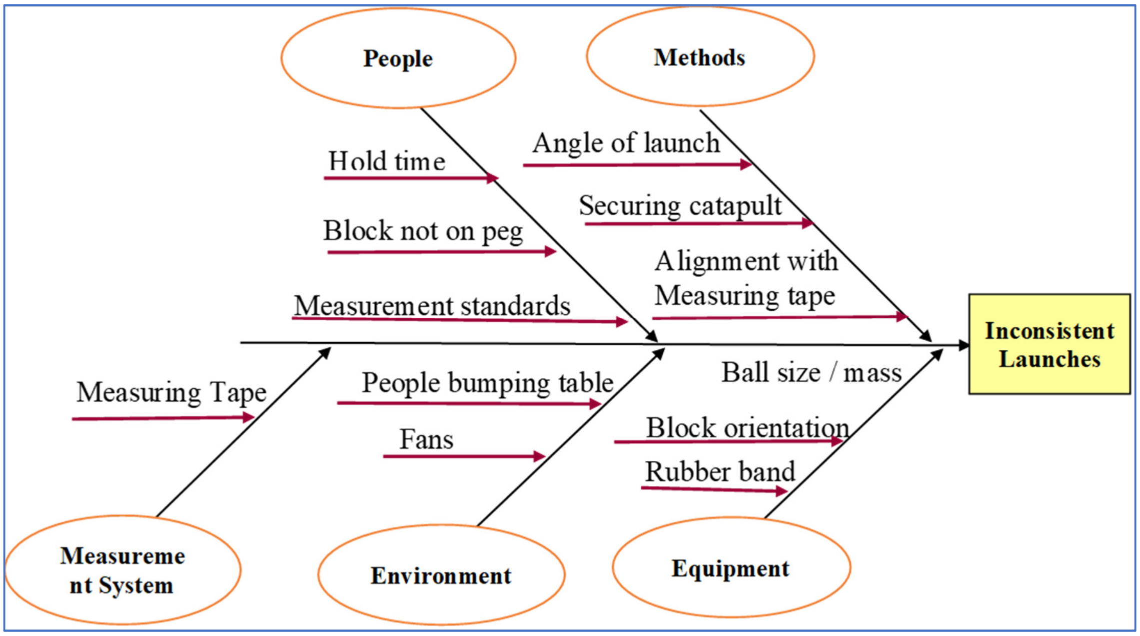


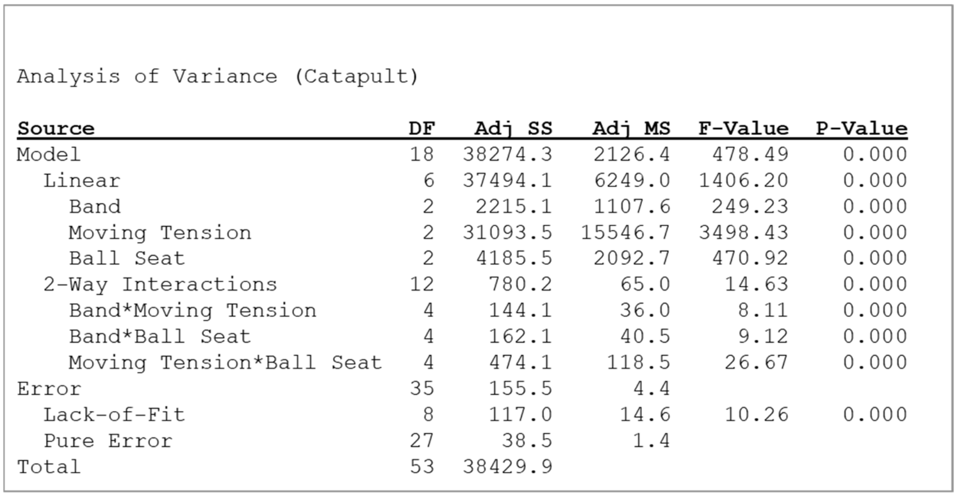
Figure 4: Brainstormed Causes of Inconsistency in Distance

Table 2: Direct Causes vs. Root Causes

Direct Cause	Root Cause
Movement of catapult during launch	No provision for securing the catapult
Alignment of tape measure	Poor configuration
Inconsistent rubber band	No marking on bands

c. Design of Experiments (DoE): This was the most challenging tool for students to use, but it helped in identifying which factors to control for minimizing variation in the distance and locating the best settings for optimum. This team used a factorial design each at 3 levels 3^k with three factors (k=3) for a total of 27 combinations. The experiment was replicated for a total number of runs (N=54). It should be mentioned here that teams were free to choose an appropriate design as long as they included at least three factors. Results of the design of experiments included analysis of variance (Table 2), factorial plots (Figure 5) and interaction plots (Figure 6). Results indicated which factors must be controlled closely (the most significant). As for interactions, and even though showing statistical significance, the contribution is minimal when compared with the main effects (controllable factors).

Table 2: Analysis of Variance



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Analysis of Variance (Catapult)

Source                           DF   Adj SS   Adj MS  F-Value  P-Value
Model                            18  38274.3   2126.4   478.49    0.000
  Linear                          6  37494.1   6249.0  1406.20    0.000
    Band                          2   2215.1   1107.6   249.23    0.000
    Moving Tension                2  31093.5  15546.7  3498.43    0.000
    Ball Seat                     2   4185.5   2092.7   470.92    0.000
  2-Way Interactions             12    780.2     65.0    14.63    0.000
    Band*Moving Tension           4    144.1     36.0     8.11    0.000
    Band*Ball Seat                4    162.1     40.5     9.12    0.000
    Moving Tension*Ball Seat      4    474.1    118.5    26.67    0.000
Error                            35    155.5      4.4
  Lack-of-Fit                     8    117.0     14.6    10.26    0.000
  Pure Error                     27     38.5      1.4
Total                            53  38429.9
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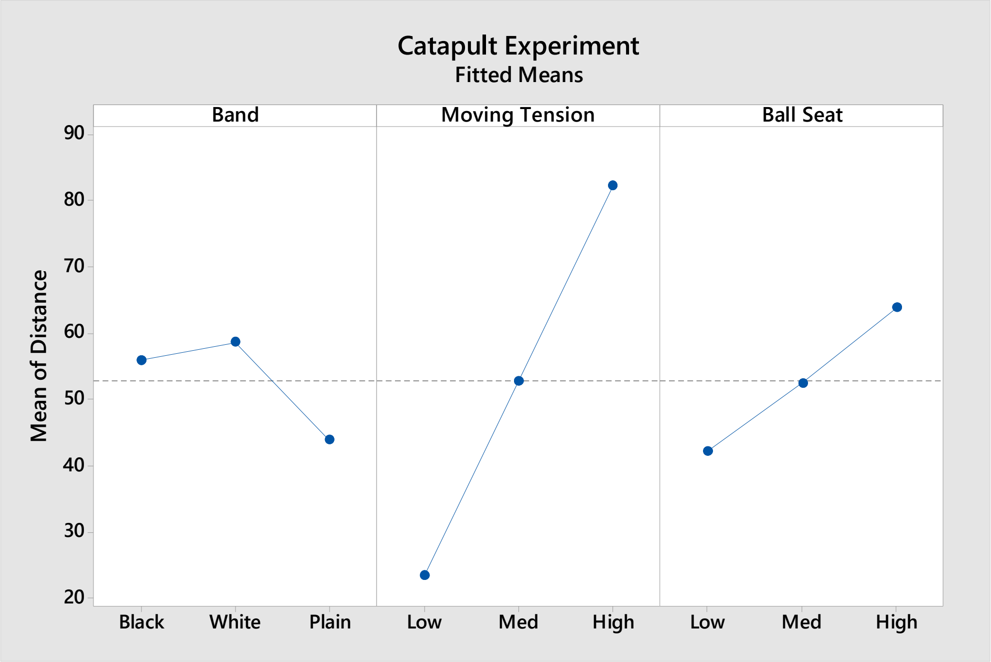

Figure 5: Factor Plots

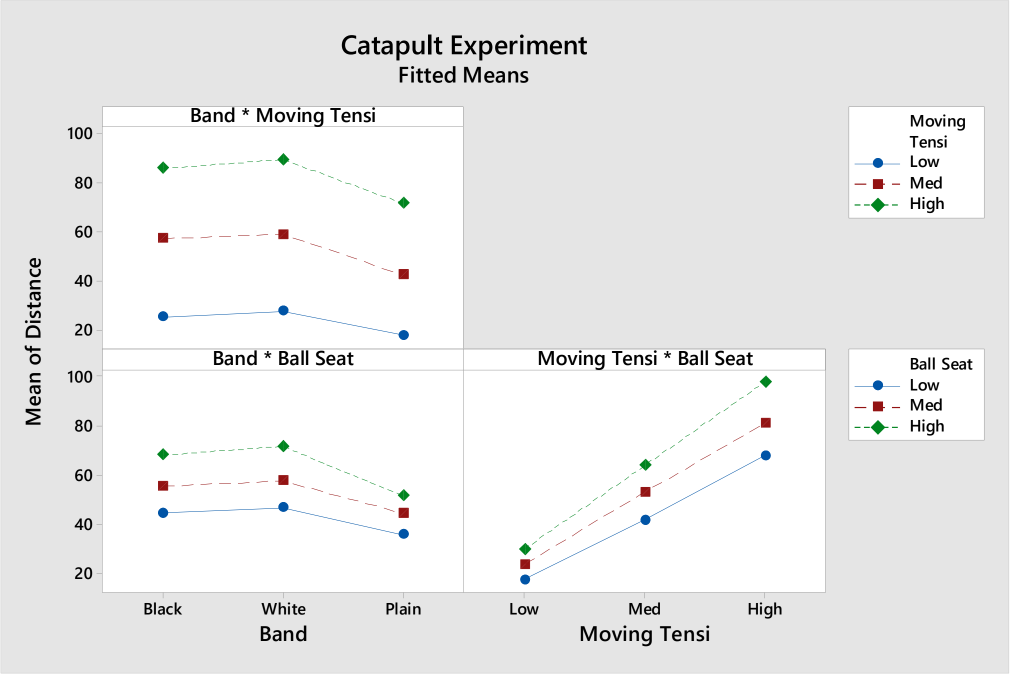

Figure 6: Interaction Plots

4. ***Improve:*** Based on analysis and interpretation of results in the Analyze phase, an improvement plan must be documented, implemented and verified. The results of this phase are typically compared against those in the *Measure* phase to see if improvements were made. For this project, the following deliverables were expected:
    a. Action Plan: A detailed plan of what actions to be taken to improve the process is prepared. For this project, the students were not allowed to make any design changes on the equipment and were only allowed to use available supplies and current factor ranges for setup. Actions included stabilizing the catapult before each launch, fixing the tape measure to the floor, and using the same rubber band.

    b. SPC Chart: After the implementation of the action plan, the process "after improvement" is sampled. Each team repeated the data collection process on a control chart similar to what was done in the *Measure* phase. Figure 7 shows process performance after improvements are made as compared to the baseline. It can be seen in Figure 7 that significant improvements were made in reducing variation and moving the process towards the target value of 80 inches.

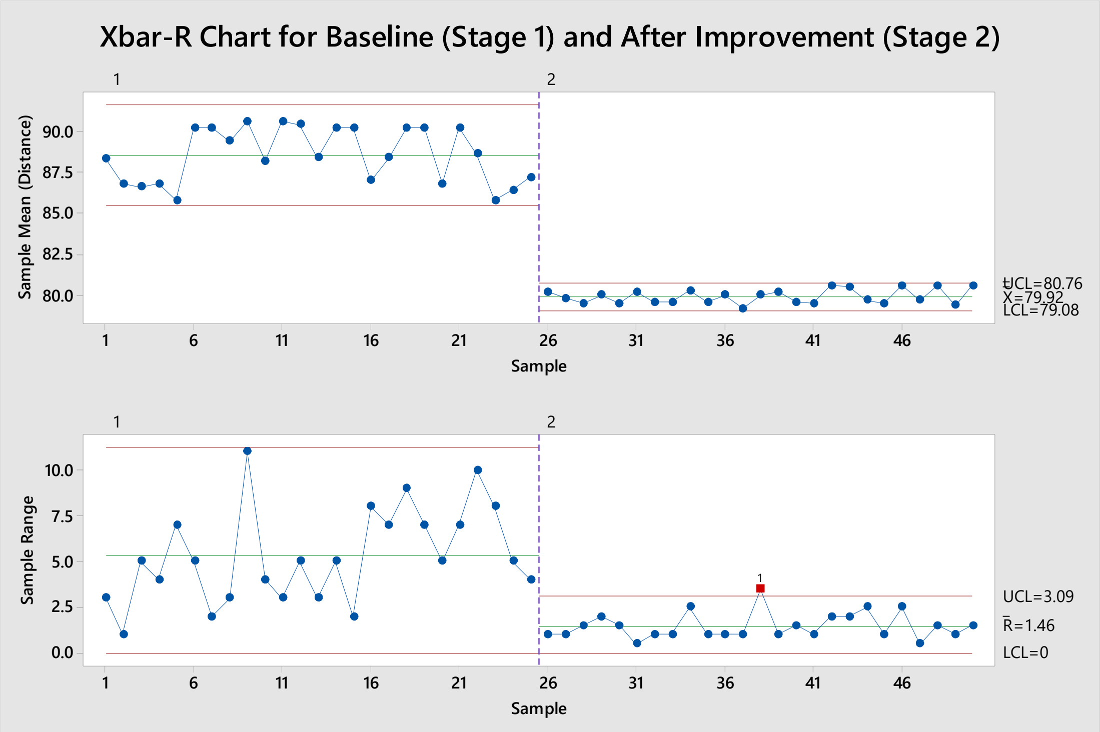

Figure 7: Process Performance Before and After Improvement

c. Process Capability Analysis: This was again run using a statistical software with "after improvement" data. Process capability indices (Cp, and Cpk), among other measures, were compared against what was obtained in the *Measure* phase. The standard deviation was reduced by about 70%. Similarly, Cp and Cpk show significant improvements but still below the standard requirements for capability of being equal or greater than 1.0. This is because the tolerance is set arbitrarily, and on the narrow (tight) side, to seek greater improvement. Table 3 summarizes statistics before and after improvement. Figure 8 displays the process capability analysis after improvement.

Table 3: Performance Comparison

Item	**Baseline**	**After Improvement**
Distance Achieved	88.5 inches	79.9 Inches
Standard Deviation	2.4 inches	0.72 inches
Capability Indices (Cp and Cpk)	Cp = 0.21 Cpk = - 0.97	Cp = 0.69 Cpk = 0.66

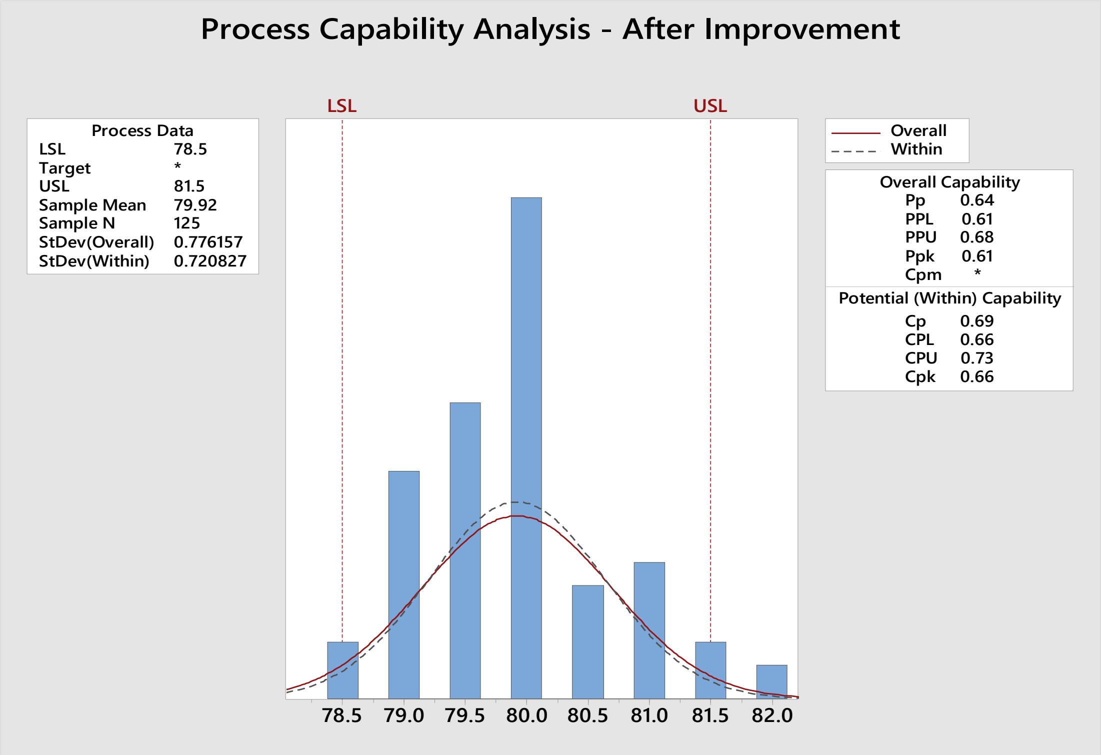

Figure 8: Process Capability Analysis - After Improvement

d. Confirmation Run: Each team had to prove that their improvements were real by conducting a confirmation run witnessed by the facilitator (professor). This information from this run was compared against the process performance after improvement to verify consistency. This is equivalent to validation of process performance after implementation of changes.

5. ***Control****:* This phase is concerned with implementing measures to ensure that realized improvements are sustained in the long run. For this project, it included the following deliverables:
   a. Control Plan / Instructions: This is designed for future users of the catapult so that the process is in control. In real-world situations, this may also be used for training purposes.
   b. On-going SPC Chart: A long-term control chart is used to plot data, so it can be studied for out of control conditions over a long period of time to ensure sustainability. At set points, say 30, 60, and 90 days, this information can be used to run and study process capability analysis and compare against original improvements.

Concluding Remarks

This project was instrumental in achieving the objectives of this course of applying knowledge of engineering and statistical fundamentals to solve technical problems and collaboratively complete its phases using applicable tools and techniques. Using the catapult as a process helped achieve our objectives in a timely manner. Students were able to identify and remove variation from the output by applying root cause analysis methodology. Teams were able to see how improvements can be made and sustained when using such methods.

Industry is always looking for incoming workforce who can lead projects, use statistical methods to analyze problems, and work in a team environment. Student surveys showed positive comments on learning quality engineering and management methods from this project when compared to traditional methods. About 87% of students indicated that this project helped them understand the concept of variation and the quality tools and techniques covered in class. In addition, 90% agreed or strongly agreed that this project helped them understand the Six Sigma DMAIC methodology. Students also indicated that they would like an opportunity to apply the techniques learned in a manufacturing environment. To do this, the department's machining, fabrication, and plastics labs may be utilized in future studies using techniques such as gages repeatability and reproducibility (GR&R) studies and design of experiments.

References

[1] Johnson, M & Kuennen, E., “Basic Math Skills and Performance in an Introductory Statistics Course,” *Journal of Statistics Education* Vol. 14, Iss. 2, 2006

[2] McLeod, D. B., "Research on Affect in Mathematics Education: A Reconceptualization," in *Handbook of Research on Mathematics Teaching and Learning*, ed. D. A. Grouws, NY: Macmillan, pp. 575-596, 1992.

[3] Finney, S. and Schraw, G., “Self-efficacy beliefs in college statistics courses,” *Contemporary Educational Psychology*, Volume: 28 Issue 2 (2003)

[4] Joan Garfield, J. and Ahlgren A., “Difficulties in Learning Basic Concepts in Probability and Statistics: Implications for Research,”, *Journal for Research in Mathematics Education* Vol. 19, No. 1 pp. 44-63, Jan 1988)

[5] National Research Council (1989). *Everybody counts: A report to the nation on the future of mathematics education.* Washington, D.C.: National Academy Press, 1989.

[6] Auster, C. J., “Probability sampling and inferential statistics: An interactive exercise using M&M’s. *Teaching Sociology*, no. 28:379–385, 2000.

[7] Helmericks, S., “Collaborative testing in social statistics: Toward gemeinstat.”. *Teaching Sociology*, no. 21, pp. 287–97, 1993.

[8] Perkins, D. V., and R. N. Saris. 2001. “A ‘jigsaw classroom’ technique for undergraduate statistics courses.” *Teaching of Psychology*, No. 28, pp.111–113, 2001.

[9] Potter, A. M. 1995. Statistics for sociologists: Teaching techniques that work. *Teaching Sociology*, no. 23: pp. 259–63, 1995

[10] Wybraniec, J., and Wilmoth, J., “Teaching Students Inferential Statistics: A ‘tail’ of Three Distributions,” *Teaching Sociology*, No. 27, pp. 74–80, 1999.

[11] Schacht, S. P., and Stewart B., “Interactive/ user-friendly gimmicks for teaching statistics,”, *Teaching Sociology*, no.20: pp. 329–332, 1992.

[12] Johnson, D, Maruyama, G, Johnson, R, Nelson, D & Skon, L, “Effects of cooperative, competitive, and individualistic goal structures on achievement: A Meta-Analysis.” *Psychological Bulletin*, vol. 89, no. 1, pp. 47-62, 1981

[13] Johnson, D, Johnson, R & Smith, K, “Cooperative learning returns to college: What evidence is there that it works?” *Change: The Magazine of Higher Learning*, vol. 30, no. 4, pp. 26-35, 1998.

[14] Curran, E., Carlson, K., and Celotta, D., "Changing Attitudes and Facilitating Understanding in the Undergraduate Statistics Classroom: A Collaborative Learning Approach,", *Journal of the Scholarship of Teaching and Learning,* Vol. 13, No. 2, pp. 49-71, 2013.

[15] Barkley, E.F., Cross, K.P., & Majro, C.H. *Collaborative learning techniques: A handbook for college faculty*. San Francisco, CA: Jossey-Bass, 2005.

[16] Anderson-Cook, C., Hoerl, R., & Patterson, A. (2005). "A Structured Problem-solving Course for Graduate Students: Exposing Students to Six Sigma as Part of their University Training," *Quality and Reliability Engineering International*, 21, pp. 249-256, 2005.

[17] Castellano, J., Petrick, J., Vokurka, R., & Weinstein, L, "Integrating Six Sigma Concepts in an MBA Quality Management Class," *Journal of Education for Business,* 83, pp. 233-238, 2008.

[18] Cudney, E.A. & Kanigolla, D., "Measuring the Impact of Project-Based Learning in Six Sigma Education," *Journal of Enterprise Transformation*, 4, pp. 272-288, 2014.

[19] Dinesh Kanigolla, Elizabeth A. Cudney, Steven M. Corns, V.A. Samaranayake, "Enhancing Engineering Education Using Project-based Learning for Lean and Six Sigma", *International Journal of Lean Six Sigma*, Vol. 5 Issue: 1, pp.45-61, 2014.

[20] Besterfield, D., *Quality Improvement*, 9th Edition, Pearson, 2012.