INCORPORATING SIX SIGMA METHODOLOGY TRAINING
into Chemical Engineering Education

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Six Sigma is a buzz term in today's technology and business worlds. In organizations like Motorola, GE, DuPont, 3M, IBM, Dow Chemical, and PPG, Six Sigma means a measure of quality that strives for perfection.[1] Statistically, it means reducing the process variation so that ±six standard deviations lie between the mean and the nearest specification limit. Under the Six Sigma control, the defect probability is 3.4 per million.[1, 2] Six Sigma methodology has been successfully applied to manufacturing (especially chemical and related manufacturing), to research and development, and to business and financial services.

Six Sigma methodology combines elements from several quality movements with advanced statistical methodology. It is a comprehensive tool combining business concepts with technical and leadership skills, and thus it is suitable for professionals at all levels: managers, engineers, and scientists. Recently, there has been great interest in initiating Six Sigma training in college education. This paper reports the success of incorporating Six Sigma methodology into a traditional chemical engineering course, Engineering Experimentation, at Texas Tech University.

CHE 3343/4372, Engineering Experimentation, is a traditional undergraduate elective course in the chemical engineering curriculum at Texas Tech University. The original catalog listing is "strategy in experimentation; planning efficient experiments; analysis of data, interpretation, and presentation results." The course provided an excellent opportunity to incorporate Six Sigma methodology training into traditional engineering education. In practice, the instructor starts the course with an introduction of the fundamentals of Six Sigma methodology, emphasizing the D.M.A.I.C. process that refers

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to Define (D), Measure (M), Analyze (A), Improve (I), and Control (C).[3] The course is then organized to discuss various methodologies and tools in each process stage. For example, moving range chart/individual chart and range chart/X-bar chart are heavily emphasized to evaluate measurement systems in the process stage of *Measure* (M). The tools in the process stage of *Analyze* (A) overlap with various classical topics in Engineering Experimentation, including: design of experiments (DOE) and analysis (focused on two-level full, half, and highly fractionated factorial designs and analyses), residual and model adequacy analyses, regression model, and confidence levels. Apart from technical content, it is worthwhile to note that a small fraction of Six Sigma management and business concepts are also addressed, mainly in the Define stage. For example, we have discussed a S.M.A.R.T. goal (refers to a goal that is specific, measurable, agreed upon, realistic, and time bounded), thought map (a road map that is composed of different paths of questions), Six Sigma team development, and effective meeting management. A summary of the different topics discussed in each stage of the course is shown in Figure 1. As a more specific example, the instructor included a request to write a S.M.A.R.T. goal for this course in the first homework assignment. The students, working in a group format, answer questions about the course including: what is to be accomplished (S, specific), what level of improvement is needed (M, measurable), what do we agree upon as a team (A, agreed upon), whether the goal can be accomplished by the given available resources (R, realistic), and what the expected dates for major milestones are (T, time bounded). The full D.M.A.I.C. process is then practiced through a formal Catapult Project, discussed later, accounting for 15% of the final grade.

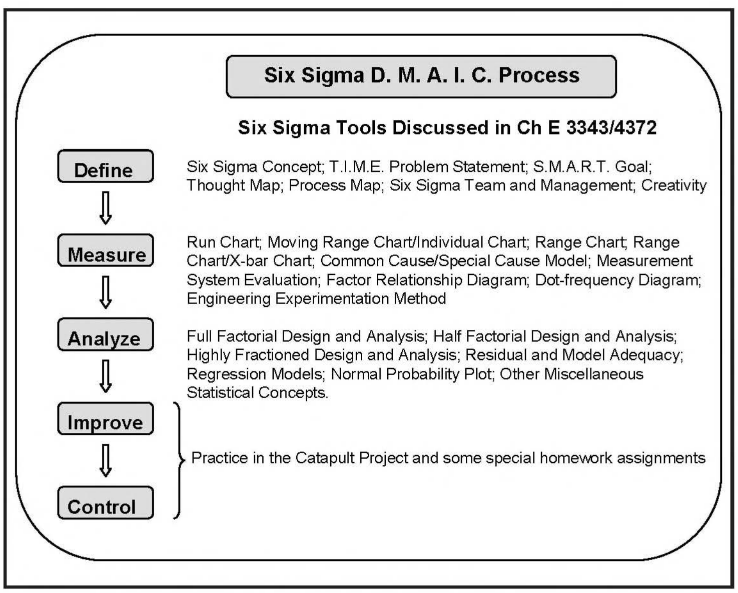

Figure 1. *The Six Sigma D.M.A.I.C. process and different tools discussed in CHE 3343/4372.*

SPECIAL HOMEWORK ASSIGNMENTS

The homework assignments in CHE 3343/4372 include the problems in the textbook *Design and Analysis of Experiments*[4] and special problems generated by the instructor. For example, the instructor provided raw data of several projects in CHE 4232, Unit Operations Laboratory (permitted by the class and the instructor Professor T. Wiesner), and requested students perform new analyses using the tools learned in CHE 3343/4372. Such assignments give students opportunities to work on practical problems related to other chemical engineering subjects and, more importantly, allow them to practice the Six Sigma methodology by solving practical chemical engineering problems. In addition, the instructor typically has several nontraditional homework assignments, such as a card-drop exercise related to variation and creativity, a paper airplane mini-project using a 2^2 full-factorial design to study the influence of airplane weight and launching angle on landing distance, and another card-drop exercise to conduct a 2^3 full-factorial design to study the influence of card weight, surface area, and releasing height on target landing.

THE CATAPULT PROJECT

"Tell me, I'll forget; show me, I'll remember; involve me, I will understand."[5, 6] Without doubt, designing and practicing are the heart of engineering majors. This is an important element in CHE 3343/4372, Engineering Experimentation. A formal Catapult Project assignment, which includes an individual project report, a group presentation, and a group competition, has been assigned for the last four successive years and counts 15% toward the total grade. Catapults are used by more than 200 companies as a training aid in Six Sigma methodology training. A snapshot of the catapult used in CHE 3343/4372 is shown in Figure 2. The project includes four major elements. First, the students are assigned to work in project teams (three to four students per team) to investigate the performance of their catapults including evaluating the measurement system and performing factorial experiments to determine the major influencing factor(s). Second, each student works independently to analyze the collected raw experimental data and submit a formal individual project report. Third, the project team regathers and finalizes the developed model for performance prediction and makes a formal project presentation to the entire class. Lastly, the team will use its developed model for a project competition. During the project competition, the instructor will place the target at a random location within a defined target area and each team needs to launch the ball within three minutes with the goal of hitting the target. Figure 3a shows a brief map of the setup in the project competition and Figure 3b is a snapshot of a ball approaching the target in a 2004 class competition.

The Catapult Project has given the students a unique opportunity to practice the Six Sigma D.M.A.I.C.

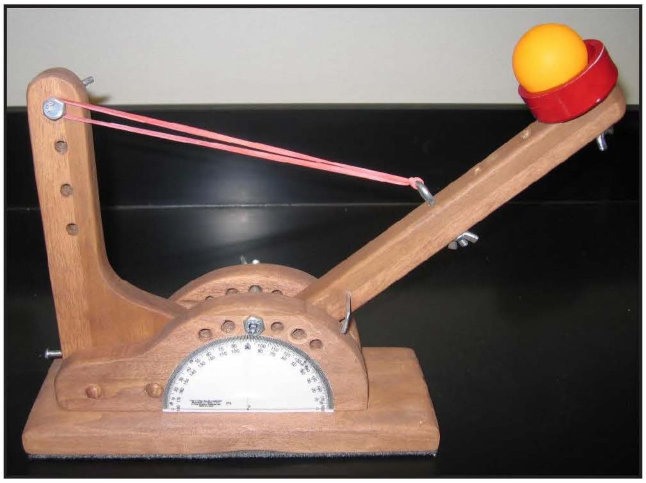

Figure 2. *A sample catapult.*

process. In the Define stage, the students practice various concepts taught in class such as defining a S.M.A.R.T. goal, organizing a thought map, and managing a project team. During the stages of Measure and Analyze, the students evaluate the measurement system and perform two-level full, half, and/or highly fractionated factorial design experiments and analyses to determine the major influencing factor(s). In addition, they will develop a regression model[4] quantitatively relating the distance as a function of setting parameters such as launching angle, type of ball, rubber band position, and stop pin position. An example of a regression model developed from a 2^3 full factorial design is:

$$\text{Distance} = \beta_0 + \beta_1(\text{parameter 1}) + \beta_2(\text{parameter 2}) + \beta_3(\text{parameter 3}) + \beta_{12}(\text{parameter 1}\times\text{parameter 2}) + \beta_{13}(\text{parameter 1}\times\text{parameter 3}) + \beta_{23}(\text{parameter 2}\times\text{parameter 3}) + \beta_{123}(\text{parameter 1}\times\text{parameter 2}\times\text{parameter 3}) + \text{error} \quad (1)$$

where β_0 is the average response from the design and β_i, β_{ij}, and β_{ijk} are calculated from the main effects of single parameters, two-way interactions, and three-way interactions, respectively. Eq. (1) is the regression model that involves all parameters and interactions in a 2^3 full-factorial design. For practicality, the students have choices of including only significant factors. The model adequacy will be evaluated by various residue analyses. Finally, the students move to the Improve and Control stage to optimize and apply the developed regression model. For example, during the project competition, each project team will measure the distance where the instructor randomly locates the target (within the target area) and use the model to decide the settings for different parameters. The accuracy and robustness of the model will directly determine whether the ball can hit the target or how close the ball is landing to the target.

It is worthwhile to note the Catapult Project also gives students an opportunity to integrate business decision making to engineering practice, as each team is allowed a maximum of 45 shots with no deduction of scores during the entire project. Upon completing the project, the students practice applying Six Sigma methodology to solve a real-life problem as well as obtaining the experience of improving the performance of the catapult while maintaining a profitable business.

THE 'JMP IN' SOFTWARE TRAINING

Other than traditional classroom lectures, the course also provides two or three training sections of the JMP In statistical software. The software is a statistical program that is widely used in Six Sigma methodology training and at companies such as Dow Chemical, Procter & Gamble, HP, and PPG. The software allows students to solve complicated statistical problems. For example, we have used the JMP In software to generate a contour plot to view all the possible combinations for desirable properties from the model developed in the factorial design.

CREATIVITY

Another learning impact of CHE 3343/4372, Engineering Experimentation, is on creativity. Most chemical engineering education focuses on problem solving based on well-established principles, placing less emphasis on creativity. Hueter states that modern people's "creative abilities increase in elementary school up to eight years old and then steadily decrease with further education, including college education."[6, 7] The importance of creativity in engineering can be summarized as follows: "Engineering is an art as well as a science, and good engineering depends upon leaps of imagination as well as painstaking care."[7, 8] Creativity is also heavily emphasized in Six Sigma methodology.[9] The project, as well as a few

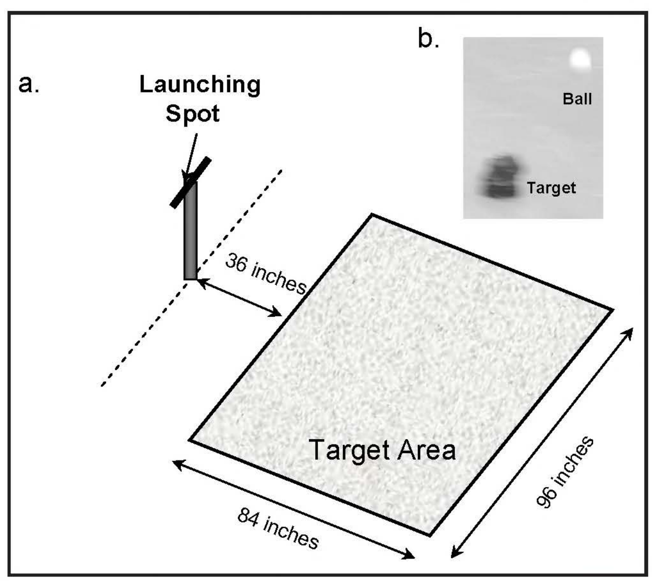

Figure 3. *(a) A map illustrating the setup for the Catapult Project competition; (b) a ball is approaching the target in an actual competition in the class of 2004.*

of the homework assignments (paper airplane competition, card drop exercises, etc.), provide students opportunities not only to practice the multidisciplinary methodology but also to maximize their potential to be creative during the exercises.

EVALUATION

The course is among the most popular electives in the chemical engineering curriculum at Texas Tech University. In the spring semesters of 2003-2006, the enrollment was 16, 26, 13, and 14, respectively. The course has received excellent student evaluation, with an average rating of 4.9/5.0, 5.0/5.0, 5.0/5.0, and 5.0/5.0 out of the 16 university-level questionnaires [scores rank from 1 (poor) to 5 (excellent)] on the instructor and course. Multiple students have said this class was their "favorite class" and the "best experience in a college course." Specific comments related to the Six Sigma training and work experience include:

- *"Taking this class has given me confidence in my ability to attack and solve problems at my new job this summer."*
- *"I think this class was one of the most beneficial courses that I have taken."*
- *"Really enjoyed this class being directly applicable to my work today."*
- *"I'm glad that the department decided to give this course, with industry changing year to year. This class will be extremely useful when we go to work!"*
- *"Great course. It should be offered every year. It helped me get my job."*

SUMMARY

We have successfully incorporated Six Sigma methodology training into a traditional chemical engineering course, CHE 3343/4372, Engineering Experimentation, at Texas Tech University. The course is structured along the Six Sigma D.M.A.I.C. process and different technical and nontechnical tools have been discussed in each stage of the process. Some of the nontraditional aspects in this course include industrial need, special homework assignments, the Catapult Project, the JMP In statistical software training, and emphasis on creativity. In addition, students have also obtained hands-on experience to practice Six Sigma methodology and a unique and integrative experience to practice engineering and business concepts simultaneously.

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