The relevant factors in the Teaching–Learning Process of Design of Experiments

Juan Sillero Pérez[1], Elsa E. R. Balmori Méndez [2]

Abstract - **Experimentation in engineering is an active experience full of excitements in order to pursuit new findings or to find new answers to certain hypothesis previously stated. The same spirit should exist in the Teaching Learning Process of Design of Experiments (DOE): active, enthusiastic, dynamic and systemic. This paper resumes the findings of an experiment aimed to discover the relevant factors in making efficient the Teaching Learning Process in a course of Design of Experiments in a bachelor curriculum.**

Using the statistical design of experiment methodology, a 2k-1 experiment was conducted (a half fraction of four factors, each with two levels and a IV resolution) in a course of 40 students arranged in 8 sub-groups. The project was developed using a six steps methodology: a) defining the problem, b) selecting the proper variables, c) designing the experiment, d) running the experiment, e) analyzing the results and f) making conclusions and recommendations.

The results was a mathematical model that expresses the desired output variable Y as a function of the next relevant factors in a Teaching-Learning process: 1) Use active didactic strategies (Problem Based Learning), 2) Deliver relatively high homework, and 3) Give opportune feed back to the individual student work performance. Controlling these elements the learning process can be successfully performed.

Index terms - Design of Experiments, Efficiency in Teaching-Learning Process, Teaching Strategies, Active Methodology in Classroom.

INTRODUCTION

The Industrial Engineering and System (IIS) undergraduate program of the University of Monterrey, recently redesigned its curriculum as a regular practice in order to revitalize the focus and core elements based on the current industrial regional and global requirements of the profession. Derived from the corresponding analysis, several aspects were contemplated to change in the new curriculum; such as the professional competence profile, the program structure, the content of courses, and the instructional strategies. One recommendation was to explore the impact of Active Learning Strategies in selected courses. Therefore, a regular engineering course from the IIS curriculum was selected to study the effect of using these Active Teaching Strategies.

A central aspect of this work is to prove the effectiveness of Active Learning Methodologies as teaching strategies in engineering courses. Active learning is generally defined as any instructional method that engages students in the learning process [1]. The core elements of active learning are student activity and engagement in the learning process. They do things and they think about what they are doing. Use of these techniques in the classroom is vital because of their powerful impact upon students learning. Felder et al. [2] include active learning on their recommendations for teaching methods that work in engineering. Active learning is contrasted to the traditional lecture where students passively receive information from the instructor.

An initial task was to select two active teaching methodologies to work with. Bonwell [3] mentions that the more important ones are: the Problem-Solving Model, the Case Study Method and the Guided Design. A faculty decision was to initiate with those related to the Problem-Solving Model for being more associated with engineering applications. One key factor in using these strategies is to change the roll of the professor who must be knowledgeable in alternative techniques for questioning and discussion and to create a supportive intellectual and emotional environment that encourages students to take risks [4].

Another important aspect is the methodology to supports the Scientific Method involved to validate the proposed hypothesis. The Design of Experiment (DOE) has been shown effectiveness as a methodology with an increasing number of applications. Initially, experimental design found applications in agriculture [5], biology [6] and other hard science [7]. It has been used traditionally in engineering [8]; but rapidly other areas discovered valuable applications such as social science, economics, behavioural analysis, business and management applications [9]. Therefore; the DOE methodology was selected to carry on this experiment in the engineering education area.

This paper presents the way of using the experimental design in order to find the most important variables in Active Learning Techniques and outlines findings of an experiment aimed to discover the relevant factors in making the Teaching Learning Process efficient. It is structured following a six step methodology: a) problem definition, b)

[1] Juan Sillero-Pérez Ph.D., Professor of the Engineering Department, Universidad de Monterrey, jsillero@udem.edu.mx
[2] Elsa E.R. Balmori Mendez Ed. D., Professor of the Mathematics Department, Universidad de Monterrey, rbalmori@udem.edu.mx

factors selection, c) design of the experiment, d) conducting the experiment, e) analysis of results, and f) conclusions and recommendations.

PROBLEM DEFINITION

The starting point of the problem definition can be the following question: Is there any improvement in the Learning Process through the use of active teaching strategies? The population under study is delimited by the students from the IIS Program, and more specifically by the student from the DOE Spring course of 2006. The general objective of the experiment can be stated as follows:

Objective: To improve the Teaching Learning Process in an typical engineering course by optimizing the impact of methodologies and teaching strategies that increases the student performance.

Scope of the project:
1. Identify the current weaknesses of the Teaching Learning Process in IIS
2. Conduct an experiment using different teaching strategies to measure their effectiveness
3. Draw specific recommendations for future process improvements.

FACTORS SELECTION

The selections of the relevant factors or variables were 1000 evaluations of the teaching process and environment in the classroom conducted by students on the Industrial Engineering Program. The evaluation was applied to all IIE curses, using an instrument with 10 different items with a relative scale of 1-5 (greater is beter). The 10 items are as follows: 1) lecture previously prepared by the professor, 2) understanding the academic material, 3) availability of academic coaching, 4) active methodology in classroom, 5) improving rezoning capabilities, 6) homework assignments, 7) fairness evaluation of exam, 8) Covering the programmed material, 9) Feedback for improvment, 10) Number of study hours devoted by the student. Using this information, a multiple regression analysis was conducted to find the best set of variables that maximize the course's intellectual stimulus as a target variable expressed by the student score grading . The regression model obtained was as follows:

$$Y = - 0.339 + 0.475X_2+0.214X_4+0.154X_{10}+0.196X_9$$

Where:
Y is the overall course evaluation
X_2 is the clarity in teaching,
X_4 is the active methodology,
X_{10} is the student time devoted to individual homework,
X_9 is the Feedback for improvement

From this previous analysis and the context of the project purpose, the selected variables to build up the experiment were: Active methodologies (Problem Base Learning and Project Development), Feedback for improvement, and Time devoted to study by the student.

DESIGN OF THE EXPERIMENT

The selected Design was a 2^{k-p} fractional factorial design with k=4 and p=1; i.e. one half fraction of a full four factors experiment. The resulted resolution is a IV. A significance level of α = 10% was taken. The 8 experimental runs were conducted with 8 sub-groups adding up a total of 40 students. Response variable, factors and levels were as follows:

Response variable: Degree of mastery of knowledge and methodology of the DOE course (grading score).

Factors: Problem Base Learning, Project development, Feedback for improvement, and Time devoted to study.

Levels: Levels for each factor are shown in Table I

TABLE I.
LEVELS FOR EACH FACTORS

Factors	Low level	High level
A. Problem Base Learning	No Problem solution used as teaching strategy	All homework using Problem solution as the teaching strategy
B. Projects development	No Project assigned f in thematic unit	One Project assigned for each thematic unit
C. Time devoted to study	Low. Without extra class work.	High Two hours extra class for each one in the classroom
D. Feed back for improvement	Low No immediate Feed Back nor suggestions for improvement of individual work	High Immediate Feed Back and suggestions to improve performance for all individual work

The statistical hypothesis testing is basically to prove the Null Hypothesis Ho. which considers that there is no effect of a given factor τ_R in the response variable Y; i.e. τ_R equal zero or, to prove the Alternative Hypothesis Ha. which assumes a value of τ_R different from Zero. Therefore, base on the above factor selection the statement of the hypothesis are:

Hypothesis A. (Problem Base Learning)
Ho: $\tau_A = 0$
Ha: $\tau_A \neq 0$
Hypothesis B. (Project development)
Ho: $\tau_B = 0$
Ha: $\tau_B \neq 0$
Hypothesis C. (Time devoted to study)
Ho: $\tau_C = 0$
Ha: $\tau_C \neq 0$
Hypothesis D. (feedback for improvement)
Ho: $\tau_D = 0$
Ha: $\tau_D \neq 0$

CONDUCTING THE EXPERIMENT

Since the two selected active teaching methodologies require a grate level of mastering the technique, a previous work shop sessions were taken by the professor until all the material and techniques were properly mastered. In a two week period all the 8 subgroups were submitted to the same academic content (learning Unit) but under different level treatments of the 4 factors as shown in the matrix design in Table II. The output variable Y comes from the average of the grading score of the five student's performance in their individual exams. The evaluation scale was from 0 to 10.

TABLE II.
PROJECT DESIGN AND OBSERVED DATA

StdOrder	RunOrder	CenterPt	Blocks	Pbl	Proj D	Time	Feed B	Y
6	1	1	1	-1	1	1	-1	9.3
4	2	1	1	1	-1	1	-1	8.4
2	3	1	1	-1	-1	1	1	8.7
8	4	1	1	1	1	1	1	9.7
1	5	1	1	-1	-1	-1	-1	7.5
3	6	1	1	1	-1	-1	1	9.1
7	7	1	1	1	1	-1	-1	8.6
5	8	1	1	-1	1	-1	1	7.3

The table also shows the standard and the run order for each arrangement. There is only one central point and all runs in one block. The same learning Unit was used to provide a unique base of knowledge and to reduce noise effects. A specialized statistical software Minitab-15 was used to design and analyze the experiment data.

ANALYSIS OF RESULTS

A regular Analysis of Variance methodology is used to identify the relevant factors that affect the output variable Y. In this case since there are not enough degrees of freedom to make all relevant calculations, then a filtering variable phase is necessary as a preliminary requirement to identify the relevant factors that affect the response variable Y. By using both, a Pareto Chart and a Normal probability Plot these relevant factors are detected.

Figure 1. depicts the Pareto Chart which shows the relevant factor and interactions by means of the bars that overpass the vertical line to the right. Factors A and C, and interactions AC and AD are relevant since overpass to the right of the vertical line corresponding to a Alfa value of 0.1

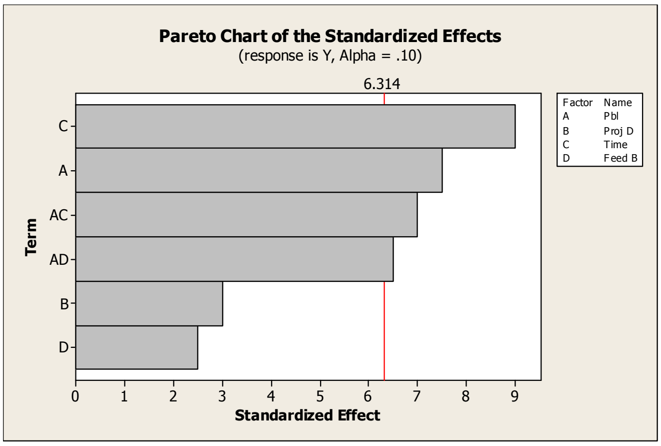

FIGURE 1
PARETO CHART FOR SIGNIFICANT FACTORS

Similarly to the previous chart, the Normal Probability Plot in Figure 2. Also shows the significant factors by means of squares.

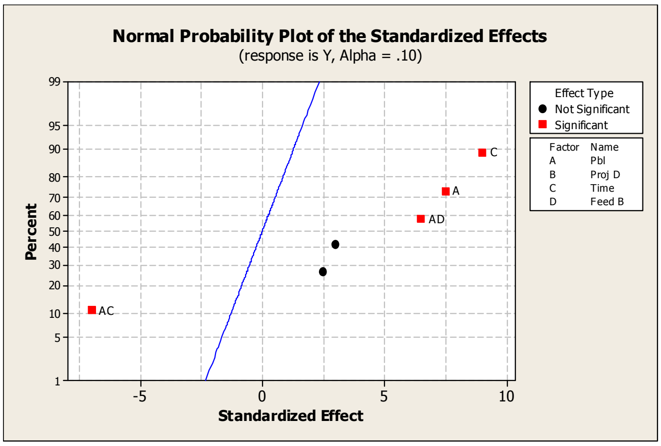

FIGURE 2
NORMAL PROBABILITY PLOT FOR SIGNIFICANT FACTORS

Once the relevant factors and interactions are graphically identified, then the Analysis of variance ANOVA and all the required calculations can be performed since now there are enough degrees of freedom. Table and all others calculations can be determined. The Figure 3. contains in the last column the p-values for each term under study which statistically determine the significance of the terms in explaining Y. Those values that result less than the alpha level of 0.10 are significant; i.e., the constant, factors Pbl, and Time, as well as Pbl*Time and Pbl*FeedB interactions.

```
Estimated Effects and Coefficients for Y (coded units)

Term        Effect     Coef  SE Coef      T      P
Constant             8.5750   0.1118  76.70  0.000
Pbl         0.7500   0.3750   0.1118   3.35  0.079
TimeE       0.9000   0.4500   0.1118   4.02  0.057
FeedB       0.2500   0.1250   0.1118   1.12  0.380
Pbl*TimeE  -0.7000  -0.3500   0.1118  -3.13  0.089
Pbl*FeedB   0.6500   0.3250   0.1118   2.91  0.101
```

FIGURE 3
P-VALUES FOR SIGNIFICANT TERMS

Figure 3. also contains the coefficients of the significant variables for the regression equation of Y which can be used to predict the its value by controlling the other independent variables. The resulted equation is as follows:

$$Y = 8.58 + 0.38Pbl + 0.45TimeE - 0.35Pbl*TimeE +0.32Pbl*FeedB$$

Another important analysis is to quantify the effect and contribution of the main effects. The Sum of Squares from the "seq SS" column in Table III can be used to calculate the percentage for each term as referred to the total SS. These percentages indicate the relevance of the significant factors and also explain their contribution for explaining the output variable Y. The percentages are as follows: a) Pbl = 23%, b) Time =33%, c) Pbl*Time = 20%, and d) Pbl*FeedB = 17%

TABLE III.
ANOVA TABLE FOR SIGNIFICANT EFFECTS

Analysis of Variance for Y, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pbl	1	1.12500	1.12500	1.12500	56.25	0.084
ProjD	1	0.18000	0.18000	0.18000	9.00	0.205
TimeE	1	1.62000	1.62000	1.62000	81.00	0.070
FeedB	1	0.12500	0.12500	0.12500	6.25	0.242
Pbl*TimeE	1	0.98000	0.98000	0.98000	49.00	0.090
Pbl*FeedB	1	0.84500	0.84500	0.84500	42.25	0.097
Error	1	0.02000	0.02000	0.02000		
Total	7	4.89500				

Figure 4. depicts the main effects of the Pbl and TimeE factors. Notice the grate slopes the more relevance of their statistical significance.

CONCLUSIONS AND RECOMMENDATIOS

There are two kinds of conclusions: a) Statistical Conclusions that allow retaking the original Hypothesis testing results and are based on the p-value statistical indicator, and b) the Practical Conclusions, that answer the questions derived from the original problem.

Based on the previous analysis, the statistical conclusions for the experiment are:

Hypothesis A (Problem Base Learning).
Since p-value for factor in the ANOVA is less than 0.10, then, there is enough statistical evidence to reject Ho.

Hypothesis B (Project development).
Since p-value for factor B is greater than 0.10, then, there is enough statistical evidence to fail to reject Ho.

Hypothesis C (Time devoted to study).
Since p-value for factor C is less than 0.10, then, there is enough statistical evidence to reject Ho.

Hypothesis D (Feed Back).
Since p-value for factor D is greater than 0.10, then, there is enough statistical evidence to fail to reject Ho.

The Practical conclusions based on the statistical results, the main effects and the sum of squares are as follows: The Degree of mastery of knowledge and methodology of the DOE course is positively affected by the teaching strategy of Problem Base Learning and also by the Time expended to study during the course. This time represents 33% of the output variable and a 23% by the strategy itself. Besides, there is a combined contribution from the Problem Based Learning Strategy and the Time expended to study, as well as, the opportune feed back by the professor to the student individual work performance which positively increase the affects on the Teaching Learning Process.

A series of recommendations derived from this study in order to improve the quality and efficiency of the Teaching Learning Process for a DOE engineering course are: 1) Promote the use of active didactic strategies (Problem Based Learning) in the teaching process, 2) Deliver rather high homework during the semester, and 3) Give opportune feed back to the individual student work performance. Controlling these elements the learning process can be successfully performed.

References

[1] Prince Michael. *"Does active learning works, A review of the research. Journal of Engineering Education"* , 93(3) , pp (233-231), 2004.

[2] Felder, R., D. Woods, J. Stice, and A. Rugarcia, "*The Future of Engineering Education: II.Teaching Methods that Work,*" Chemical Engineering Education, Vol. 34, No. 1, 2000, pp. 26–39.

[3] Bonwell, Charles C. - Eison, James A. *"Active Learning: Creating Excitement in the Classroom"*, ERIC Clearinghouse on Higher Education Washington DC. consulted april 1st in http://www.ntlf.com/html/lib/bib/91-9dig.htm

[4] Diaz, B. Frida and Herandez R. *"Estrategias docentes para un aprendizaje significativo"*, Mcgraw Hill, Mexico, 1999. 232 p.

[5] Cox, David R. *"Planning of Experiments"*, New York, John Wiley & Sons, 1958.

[6] Fisher, Ronald A. *"The Design of Experiments"*, Rothamsted experimental station 1932 annual report, Indianapolis: Hafner Press, 1932.

[7] Box, George E.P., William G. Hunter, and Stuar J. Hunter. *"Statistics for experimenters: An introduction to Design, Data Analysis, and Model Building"*, New York, John Wiley & Sons, 1978.

[8] Montgomery, Douglas C. *"Design and Analysis of Experiments"*, New York: John Wiley & Sons, 2005 .

[9] Berger, Paul D., Maurer Robert E. *"Experimental Design : with Applications in Management, Engineering and Sciences"*, Duxbury Thompson Learning , 2002.