Session 3557

Improving Student Understanding of Design of Experiments by Introducing Simulation and Analysis

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Abstract

Design and Analysis of Experiments should be more than a course for engineers. It shall become a tool that will allow the future engineering practitioner to understand, model, predict, and optimize his/her surrounding environment based on scientific procedures. In order to achieve this goal, it is important to move away from the theory-based course design towards a real-situation based course design. Several new resources might have to be used, but the expected outcome is worthy.

This paper discusses issues related to design and tools requirement for two courses, namely ESI 4224 Design of Experiments (Undergraduate Level) and ESI 6247 Statistical Design Models (Graduate Level) at the University of South Florida, Tampa, Florida. These courses focus on getting the students ready to analyze a problem, consider different solution approaches, select the optimum design, and to be able to analyze the results. The challenges faced by the students are theoretical, practical, and computational. Theoretical (statistical) issues are addressed well in class. The computational issues arise primarily due to the inadequacies of the student versions of the software packages. As a result, students are encouraged to develop their own computational aide via EXCEL templates. The practical issues associated with experimental designs are addressed through simulated experiments created using LABVIEW. One such simulated plant has 7 variables and one measure of performance to optimize. As in most real life situations, students are allowed a limited amount of experiments to screen the process, look for significant variables, and create a model for the process response. This course design approach addresses many of the outcomes and assessment criteria outlined in ABET 2000 guidelines.

I. Introduction

Challenges faced by Engineers in the coming years will require more decision-making abilities. Therefore, the connection between theory and practice in any field should be well developed in the students' mind. Any course on Design of Experiments, if well developed, should provide the future practitioner a thinking structure and a base of knowledge to understand, analyze, and improve his/her surrounding. From this perspective, the focus of Design of Experiment education, both in the undergraduate and the graduate level, should move from the understanding of statistical theory to the development of implementation abilities of the theory that is presented during the lectures.

Undergraduate education in engineering must develop a problem solver, an engineer willing to improve his/her surrounding while fulfilling organizational goals. Hence, faculty commitment to the creation of a strong bond between theory and application is required. Graduate education, on the other hand, requires the understanding of how real problems are faced to stimulate the development of new approaches and solutions applicable in real situations.

This paper presents an approach that is being followed by the Industrial Engineering Department at the University of South Florida to comply with the above vision which also agrees with ABET 2000 guidelines. The introduction of real-life type problems allows the students to develop the link between the statistical theory and its applications, and also their own design strategies to optimize a problem in a supervised environment.

II. Course Description

The strategies that will be presented in following sections were implemented in two courses:

- EIN 4244 Design of Experiments Undergraduate Level 3 Cr.
- EIN 6247 Statistical Design Models Graduate Level 3 Cr.

The outcomes of the two courses, though similar, vary in intensity, depth, and rigor. The outcomes are[1]:

- To understand the significance of experimental design and analysis.
- To learn and to be able to apply the steps required to complete an experimental design and analysis.
- To identify the types of variables in a system and associate them to different parts of the experimental model.
- To understand the fundamentals of the random and fixed effects model.
- To be able to develop relationships between means at different levels using various techniques.
- To understand and be able to apply the factorial design and analysis method.
- To understand the meaning and importance of interactions, and to be able to quantify them.
- To understand the 2^K factorial design, its applications, and its implementation and evaluation procedure.
- To understand the 2^{K-N} fractional factorial design and its application under experimental constraints.
- To understand the concepts of blocking, confounding, and aliasing. To learn how to avoid, control, and quantify them.
- To understand and be able to apply 2^K Taguchi's design.
- To be able to fit a regression model using collected information, and to determine the quality of the model that have been obtained.

- To understand the different considerations required using multiple design experiments in a constrained environment.
- To use a computer to implement different solution approaches in a multivariable problem.
- To be able to implement the complete statistical design, data collection, and analysis in a real-life constrained environment.

Objectives are assessed through the following assignments:
- Tests. Should verify the understanding of concepts and knowledge of the procedures required to analyze a given set of data.
- Homeworks. Should keep updated the professor of students' degree of achievement on proposed topics.
- Computer Project. Verify the student ability to implement a solution strategy using a computer.
- Industrial Project. The focus is to assess the student ability to identify a problem, determine factors, levels, and ranges, and appropriate selection of the response variable.
- Optimization Project. To assess the student ability to use multiple designs to screen, analyze, model, and optimize a multivariable system while fulfilling a maximum amount of experiments constrain.

The resources required for these two classes are:
- Microsoft EXCEL
- Process simulations (developed in Labview)
- Web site to post information related to class notes, projects specifications, and permanent communication with students

III. Major issues of teaching Design of Experiments

Three major issues are addressed all along the course, such that, their integration will achieve the creation of a solid theoretical and practical background in design and analysis of experiments. These three major issues are theoretical, computational, and practical.

Theoretical Issues

In general, theories presented in design of experiment courses are well developed and documented. The challenge is to select the appropriate focus and depth in the material to create the balance between statistical foundation and applicability. In a general sense, topics are included within the following areas:
- Underlying concepts of analysis of variance (random error, variables)
- Design strategies (factorial, fractional, Taguchi's)
- Analysis of data (significance of factors, α and β errors, sample size, mean comparison)
- Creation of models (regression analysis, curve fitting)

Most of the material available in the textbooks gives support to these topics. However, given the fact that the starting point in any book problem is a table of data requiring analysis, design abilities are difficult to practice and improve.

Computational Issues

Computer has become the first-hand tool for engineers in any field. From the design of experiments course perspective there are software packages that assist the student in experimental design, data storage, calculations, ANOVA construction, and plotting. However, there are two main disadvantages in classroom usage of this type of software:

- Student versions of DOE software usually have a rigid structure that limit the variety of problems that can be solved.
- Statistical software is not as popular as CAD, CAM, and simulation software. Therefore, the probability that a young engineer can find the same software that he/she learned at school is very low.

Given the scope of both undergraduate and graduate education in design of experiments, a general-purpose software, such as EXCEL, serves the purpose of providing support for numerical calculation and plotting while demanding student understanding of the solution structure, sequence, and interdependence. Additionally, the limitation in the type of calculations and comparison is almost none existent within the desired topics. The use of automatic ANOVA generators from data lead the students to think that analysis of experiments is about formulas, which is a big mistake. There is a time for the use of any automated-solution package: when the intelligence of the user is superior to that of the software. Otherwise, the obtained solution becomes dogma.

The type of assignment that is given during the semester to stimulate the use of computers as a support tools is the design of a template in EXCEL. As the students are presented with different topics, their task is the creation and improvement of a template that will help to solve problems associated to the topic. The increasing requirements from the first template take the students through a learning experience that emphasize the relationship between the preceding knowledge and current topic. At the same time, they reinforce previously acquired knowledge and abilities.

The typical architecture of the EXCEL template that students obtain at the end of the course is presented in Figure 1.

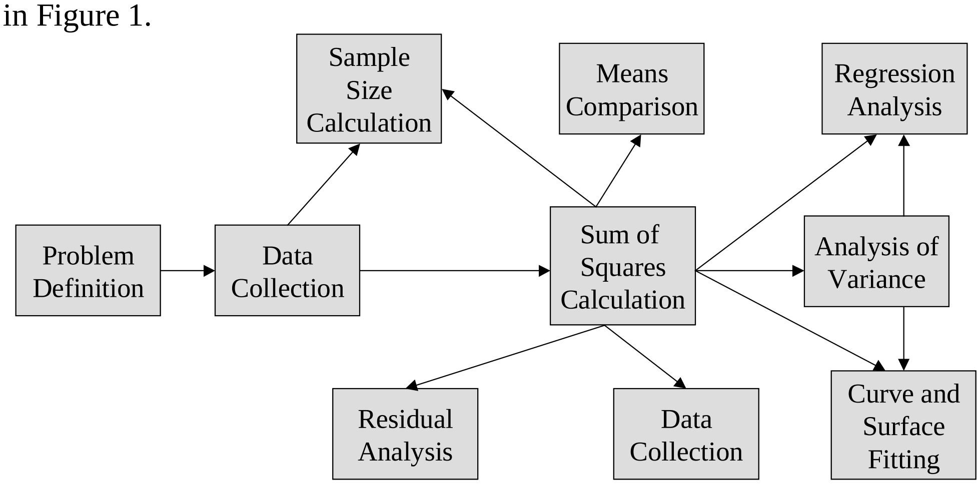

Figure 1. Architecture of EXCEL Template for Single Factor Experiment

Practical Issues

Although theoretical and computational issues are important in “Design and Analysis of Experiments” education, they are not enough to allow the complete understanding of the word “design” in “Design and Analysis of Experiments.” It is necessary to face students with a problem where they have the opportunity to apply the fundamental concepts of experimental design, namely problem definition, variables selection, factors and levels, and experiment design[2]. Then they can use computer support to perform numerical calculations and analysis. Two different types of such assignments are presented to the students: industrial project, and simulated plant optimization.

In the industrial project, students work in teams and look for a manufacturing, commercial, or service enterprise. They must identify a problem, define the problem statement, limit the scope of the study, and define a general solution strategy including estimated time and cost. Next step is to select sample size, factors and levels, response variables, and experimental design. The remaining steps include data collection, numerical calculations, analysis, and a suggested course of action. Students prepare a report and make a formal presentation of their problem, findings, methodology, and conclusions. Most students experience a difficulty in collecting all the data that they expect, which is not to far from reality. This is an experience that no book can teach.

The plant optimization project is based on simulations created in LABVIEW[3]. In such simulations, a process plant with a given response variable is made available to the students to operate. There are several variables (most times 6 or 7), some quantitative (such as time, pressure, level, temperature, concentration), some qualitative (manufacturer, unit, operator, batch). Students are given a maximum amount of experiments to run. The goal is to find the appropriate operating conditions to either optimize the response variable or to meet certain specification while optimizing a cost function. They are encouraged to use screening designs (fractional factorial, Taguchi’s) first and full factorials at last. From the first set of runs it is expected that they will eliminate non-significant factors. From the latter experiments they must obtain significant factors and two-factor interactions (and their order of significance). Students should also use this data to build a model to perform the optimization.

One such simulation is presented in Figure 2. In this situation the response variable is the viscosity obtained in oil after processing. The process variables that can be manipulated are maximum pressure, temperature, residence time, maximum level, manufacturer, and plant. There is a limit of maximum 64 experiments available. Students must find significant factors and interactions, build a model, and select the operating conditions that maximize the viscosity. Most of the times, students select either a 2^{6-1} or a L_{16} design to screen the system. Then they run a factorial experiment with 3 levels to test for two-factor interactions and linear and quadratic behavior. Later, they build the model and, if some experiments are left, they run experiments at the selected conditions to estimate the standard deviation at this particular condition. One of the great achievements of this experience is that students are able to feel and understand the reasons why full factorial designs are expensive in many senses, and how a fractional design can provide a cost-effective solution in many cases.

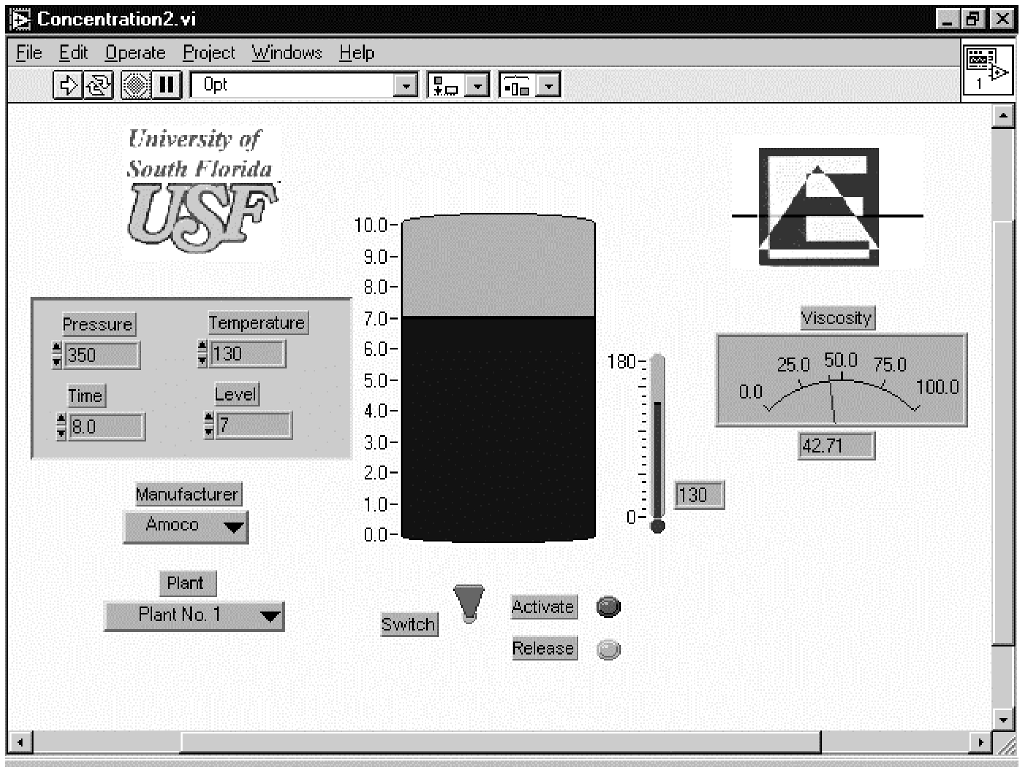

Figure 2. Oil Plant Simulation Front Panel

IV. Conclusions

The implementation of these strategies during the previous year, both in undergraduate and graduate level lead to the following revelations:

- It is required to integrate theoretical, computational, and practical issues in the design of experiments curriculum to develop not only knowledge but also abilities in the students.
- Computer should be a tool to support numerical calculations and plotting, but should not be used to run an automatic ANOVA generator that keeps the students from understanding the design and analysis' internal structure. An appropriate tool for this purpose is EXCEL.
- Practical issues should be addressed in the curriculum, and practical projects assigned. Students should be encouraged to face the challenges of a complete experiment design, not only the numerical calculation part of it. Both plant simulations and industrial projects can help students to develop the sense of what it takes to solve a problem using "Design and Analysis of Experiments."

Bibliography

1. "Design of Experiments" Outline. Industrial and Management Systems Engineering Department. University of South Florida. 1998.
2. Montgomery, D. "Design and Analysis of Experiments". John Wiley and Sons. 4th Edition. New York, 1997.
3. "Labview 4.1 User Manual". National Instruments Corporation. January, 1996.

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Design of experiments or DoE is a common analytical technique to design the right testing framework. It is is widely used in testing framework.Â To understand, how design of experiments can help one in limiting the number of combinations that need to be tested, one needs to understand the effects of each attribute or level separately and the effect of these attributes acting in tandem. Design of Experiments without Interaction Effects. The levels of a particular parameter or factor are used as variables for constructing the response function for each combination listed in Table-1. For example the factor â€œPosition of pictureâ€ comprises of 3 levels. Design-of-experiments (DOE) can be programmed ahead of time to step the process through a series of run conditions for proof of concept batches and clinical trials. They can also be used when developing a new process or product to determine the optimum set of run parameters. The DOEs are sequenced through various sets of design conditions and control options with batch Phases.Â The model can be used to understand the influence of the experimental parameters on the outcome and to find an optimum for the process. Custom-designed software can be used to create the experimental designs, to obtain a model, and to visualize the generated information.Â We've already had an introduction to statistical analysis and statistical process control in earlier chapters. This tutorial reviews the design and analysis of simulation experiments. These experiments may have various goals: validation, prediction, sensitivity analysis, optimization (possibly robust), and risk or uncertainty analysis. These goals may be realized through metamodels. Two types of metamodels are the focus of this tutorial: (i) low-order polynomial regression, and (ii) Kriging (or Gaussian processes). The type of metamodel guides the design of the experiment; this design fixes the input combinations of the simulation model. However, before a regression or Kriging metamodel is applied, the Improving Student Understanding of Design of Experiments by Introducing Simulation and Analysis. Marco E. Sanjuan, Tapas K. Das Universidad del Norte / University of South Florida. Abstract. Design and Analysis of Experiments should be more than a course for engineers. It shall become a tool that will allow the future engineering practitioner to understand, model, predict, and optimize his/her surrounding environment based on scientific procedures. In order to achieve this goal, it is important to move away from the theory-based course design towards a real-situation based course design. Sever