2006-84: TEACHING A WEB-BASED GRADUATE COURSE ON TAGUCHI METHODS

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Introduction

The University of Wisconsin-Platteville campus is located on the western edge of the city of Platteville (population 10,000) in southwestern Wisconsin. The university traces its origins to the Platteville Normal School, which was established in 1866, and the Wisconsin School of Mines, which was established in 1907. Today, the university is a multi-purpose, coeducational institution with an on-campus enrollment of more than 5,000 students. The university offers majors and minors in 50 academic fields, and is organized into three colleges: (1) College of Business, Industry, Life Science, and Agriculture; (2) College of Liberal Arts and Education; and (3) College of Engineering, Math, and Science.

The concept of offering a degree at a distance, or an extended degree, was first initiated by University of Wisconsin System administration in the early 1970s, in an effort to extend educational opportunities to adult students throughout the state of Wisconsin. In May 1976, the University of Wisconsin System regents approved the establishment of three different extended degree programs, each to be offered at a different campus in the University of Wisconsin System. The University of Wisconsin-Platteville Extended Degree in Business Administration first enrolled students residing in Wisconsin in 1979.

In 1996, the UW-Platteville Extended Degree Program extended its reach to adults throughout the United States. In 1999, the Extended Degree Program furthered its reach worldwide and became part of the University of Wisconsin-Platteville Distance Learning Center. In 1999, both print-based and online courses for the Business Administration program were offered, and three 100% online Master's degree programs were developed in Criminal Justice, Project Management, and Engineering. The programs are available to students worldwide.

Master of Engineering (MOE) online program at the University of Wisconsin-Platteville is a web-based program designed to respond to a need expressed by industry: an advanced engineering degree without employee relocation. The MOE program offers advanced course work but no thesis. Currently, there are two emphasis areas offered: Applications of Engineering Management and Engineering Design. Applications of Engineering Management provides the engineering skills that are needed in managing technical projects, whereas the Engineering Design emphasis provides in-depth technical knowledge to enhance the student's ability to design engineering solutions. In addition to courses within a technical area of emphasis, the Master of Engineering program provides education for professional development in the areas of mathematics, technical communications, computer applications, and engineering management.

The MOE degree requires the completion of a total of 30 credits (10 courses):one course in mathematics (MATH 5230 - Linear Algebra, or MATH 6050 - Applied Statistics for Engineers), one course in computer applications (CEE 7830 - Optimization with Engineering Applications), one course in technical Communications (COMM 5010 - Business Communications, COMM 7330 - Organizational Communication, or ENGL 5000 - Technical Writing), one course in engineering management (PM 7010 - Project Management Techniques), three courses from a single emphasis area, and three open technical elective courses. The MIE 7440 – Taguchi Methods of Designing Experiments course is one of the courses available to students in the Engineering Design emphasis area in the Master of Engineering Program and is a technical elective in the Master of Science in Project Management Program.

MIE 7440 Taguchi Methods of Designing Experiments

This course was developed in 2001 and made available online with the assistance provided by the University of Wisconsin Learning Innovations (UWLI). It was taught using the Prometheus course management system once. In 2002, the course was move to the Blackboard course management system. It was taught using the Desire-to-Learn (D2L) course management system from 2003.

This DOE course provides experience in planning, conducting, and analyzing statistically designed experiments using the Taguchi methods. The primary objective of the course is to educate and train students in the quantitative and qualitative methods for quality planning, measurement, analysis, improvement, and control. This objective is achieved using textbook #1 - *Design of Experiments Using the Taguchi Approach*, by Ranjit K. Roy, John Wiley, 2001 (3rd printing) - which deals with the Taguchi approach to improve quality of products and processes. This textbook illustrates application of Qualitek-4 software for Taguchi methods. Practical examples and case studies are used to illustrate how the quality of products and services may be made robust. The Qualitek-4 and Minitab statistical software are used to solve typical problems from manufacturing and service industries.

The secondary objective of the course is to introduce the concept of dynamic characteristics in applying Taguchi methods. The only textbook on this topic is the textbook #2 for the course, *Taguchi Methods for Robust Design,* by Yuin Wu and Alan Wu, ASME Press, 2000. Students gain exposure to the entire spectrum of robust design and master its application. The focus is on preventing quality problems in the early stages of product development /design, and using the dynamic signal-to-noise (SN) ratio as the performance index for robustness of product or process functions. Methods of data collection and analysis are illustrated through case studies of parameter design.

The prerequisite background is a basic working knowledge of statistical methods. A formal course in engineering statistics at the level of MATH 4030 or MATH 6030 or MATH 6150 is the official prerequisite. MATH 4030, MATH 6030, and MATH 6150 are courses available at UW-Platteville and these calculus-based courses have the same title - Statistical Methods with Applications. The instructor may waive the prerequisite requirement for students with considerable practical experience in the application of statistical methods. Students will need to know how to compute and interpret the sample mean and standard deviation, have previous exposure to the normal distribution, be familiar with the concepts of testing hypothesis (the t-test, for example), constructing and interpreting a confidence interval, and model-fitting using the method of least squares. Most of these ideas will be reviewed in the course as they are needed.

Opportunities to use the principles taught in the course arise in all phases of engineering work, including new product design and development, process development, and manufacturing process improvement. Applications from various fields of engineering (including chemical, mechanical, electrical, materials science, industrial, etc.) are illustrated throughout the course. The course schedule and outline contains assigned reading topics from textbook #1, textbook #2, and suggested homework problems. In addition to the textbook reading assignments, students use the supplemental material and suggested Web sites posted online.

Eight equally weighted individual assignments determine 20% of the course grade. The term project determines 30% of the course grade. Two equally weighted tests determine 40% of the course grade. Eight equally weighted group discussions determine 10% of the course grade.

Term Project Planning and Organization

The term project is divided into four term project activities, TPA1, TPA2, TPA3, and TPA4, each with specific deadline for completion. These activities require the creation of a student profile online, review of prior student projects, review of software, planning the project, conducting experiments, applying statistical tools to analyze test data, and interpreting test results to improve a product or process. A final report and a PowerPoint presentation are required.

The TPA1 is designed to enable students to get acquainted with each other so that project groups consisting of two or three students may be formed within the first two weeks of the course. In addition, this activity allows students to become familiar with the course management system. All students must post individual profile (personal webpage) at the website for the course. The profile must contain information about experience, current position, and reasons for taking this course so that students may get to know each other. The profile is expected to provide name, nick name, picture, home address, schools attended, educational background, professional and personal experience, hobbies and interests, e-mail address, phone number, and availability (days and times) for online chat. Students are reminded that not all the information is absolutely necessary and each student may provide whatever information each one is comfortable with. The instructor uses the above information, schedules an online chat session in the virtual classroom, and forms project groups in consultation with students. Sometimes, one or two students prefer to complete the term project alone and that is permitted by the instructor.

TPA2 is designed to provide opportunity for students to work individually or in groups to review a journal paper on and application of the Taguchi methods and compare software for Taguchi analysis. The instructor provides a collection of about twenty journal papers on the applications of Taguchi methods in diverse fields of science and engineering. Students are also encouraged to locate a paper published in a journal or a trade magazine summarizing the application of Taguchi methods. The paper must deal with the design or improvement of a product or process using the Taguchi Methods. Students are required to submit biweekly progress report on the review the paper and submit a final review report by summarizing the design factors, noise factors, quality characteristics, experiments, experimental data, analysis, and final conclusions. Most importantly, students are required to summarize how the paper applied various concepts taught in the course. What orthogonal array was used? Was the array modified for special factor levels in the application? Were the experiments replicated or repeated? Did the authors perform the study as outlined in the textbooks? If the authors followed a different approach, state what the authors did differently. Do students agree with the way the experiments were conducted and analyzed? What did students like about the analysis? What other analyses would students have done? Do students have any ideas to improve the study? What models studied in the course were used in this paper? What aspects of the design or analysis do students disagree with in this paper? The paper review forms the foundation for the selection of a term project to be completed by students. This term project activity, TPA2, involves also the comparison of the Qualitek-4 software with at least one other software for Taguchi methods. Students are expected to compare cost, ability to perform S/N ratio analysis, ability to use the OEC (Overall Effectiveness Criterion), ability to deal with dynamic characteristics, and five other software evaluation criteria defined by students.

In the term project activity TPA3 students apply the guidelines, provided in Chapter 1 of textbook #1, for planning Taguchi studies and follow the example projects in the last few chapters of the same textbook. Students develop and ssubmit a plan for the term project along with a Gantt chart that defines the timeline for the project activities. The project plan includes definition of factors, factor levels, response variables, units for each, constraints (budget, time, scheduling, machine time, etc), noise variables, levels for noise variables, selection of inner orthogonal array to study factor effects and variable interactions, selection of outer orthogonal array, QC, OEC, choice of sample size for experiments and the method of analysis. The instructor works with students to modify the plan, if necessary.

The term project activity, TPA4, consists of conducting replicated or repeated experiments, collecting data, analyzing experimental results using statistical methods, interpreting results, optimizing the product or process, submitting a report, and giving online presentation. The project report includes factors, factor effects studied, factor interactions studied, how factor levels were chosen, noise factor, noise factor levels, replication or repetition of experiments, sample size, QC, OEC, analysis, ANOVA, pooling of factors, signal factors, static or dynamic QC, experiments, data collected, etc. Students are expected to justify the selection of sample size, replication or repetition of experiments, choice of DOE model, and software used for analysis. The optimal level for each factor, the prediction equation, the confirmation experiments, and all other details taught in the course must be included in the final report and the final presentation file.

List of Student Projects

The enrollment in the course has varied from one to three. A total of five student projects have been completed in this course from 2002 through 2005. These projects are: Pressure vessel capability study, Hydrostatic Pump Port Plate Optimization using Taguchi Methods, Maximize network performance while minimizing cost control Factors, Analyze and improve golf swing, and the Design of a precision transducer. A few of these projects were actual work related applications for the respective students. The following student project description is from the final report submitted by Mr. John McDaniel in 2002.

Sample Student Project

In the design of a precision transducer many factors affect output. These factors include scale design, capacitor values on the PCB, manufacturer, scale materials, gap between readhead and scale and machine used for performance tests. Of these factors, the machine used for tests and product manufacturer are noise factors because we are forced to use certain manufacturers, and there are limited machines used for testing the devices. There are also several quality characteristics (QC's) that need to be studied, preferably simultaneously, that are used to determine product viability. These QC's include signal strength, measured in mV/V (output/ input), battery life, measured in hrs. and product accuracy, measured in microns. Each QC must be considered when determining the final product design. Signal strength is weighted at 35%, accuracy is weighted at 45%, and battery life is weighted at 20%.

In addition to finding the design yielding the best S/N (signal-to-noise ratio) value the individual characteristics must be studied because accuracy must be below a maximum value of 6 μm, battery life must be more than 1600 hrs. and signal strength must be greater than 7 mV/V. Once an optimal design is determined through use of S/N values another set of tests must be done to verify that the chosen factors yield acceptable results at or exceeding those determined as the product minimums/maximums. As is apparent from the relative weights of the QC's, the customer would like to have the most success in making a transducer with better relative accuracy than one with better relative battery life or signal strength. Accuracy is what impresses customers, but signal strength and battery life are necessities that are not seen by the consumer but do carry importance.

The potential design factors include readhead data processing chip, scale design, capacitor values on the PCB, manufacturer, readhead gap, roll/pitch/yaw of readhead relative to the scale, scale material, circuitry metal, substrate material, test machine and inductor used on the readhead. Of these factors, many are eliminated by process knowledge. For example, past versions of the product have shown that using copper circuitry yields the highest signal strength so it is removed as a factor for consideration. In addition using a substrate made of shredded plastic composite yields the best results for signal strength and accuracy and does not affect battery life. Therefore a composite substrate is used.

The factors chosen for study, as mentioned in the problem statement are capacitor values on the PCB, manufacturer, scale metal, scale design, gap between readhead scale and test machine used to test performance. All other factors are removed from test consideration. The noise factors are the manufacturer and machine used for test. All factors affect the QC's under study. For example, a capacitor value may lead to a rapid battery drain, low signal strength but great accuracy as the capacitor has the ability to drain current, dampen signal or produce an ideal input signal.

Three levels will be studied for each factor. The following table shows the factor and their three levels. The noise levels will be held to two.

Factor	Level 1	Level 2	Level 3
Capacitor Values Scale Metal Scale Design Gap	100μF Copper 3mm .3mm	150μF Gold 4mm .4mm	300μF Standard 4.5mm .5mm
Noise Factors			
Manufacturer Test Machine	A 1	B 2	

Table 1. Factors and levels.

There are three response variables that must be considered in the overall product design. The response variables or QC's are signal strength, accuracy and battery hrs. The QC's will be studied using QT-4 software and the multiple criteria OEC (Overall Effectiveness Criterion) using the weights stated above. These response variables are largely customer mandated but the relative weights were determined through planning and practical considerations. An L-9 array was selected for the experimental design. The noise factors will be accommodated by an L-4 outer array.

The S/N ratio analysis shows that using a capacitor value of 150μF, gold as the metal used on the scale, a 4.5mm scale design and gap of 4mm will result in the most robust design given the desired relative weights of the response variables. Using these levels in the design yields S/N ratio of 38.08. Since interactions between some three level factors are not negligible it may be beneficial to study these further possibly by reducing the tests down to two-level designs. In particular, interactions between capacitor value and gap, scale metal and scale design and scale design and gap should be studied further if time and costs allow. After these tests are performed, confirmation tests should be run as well to validate the results obtained in this and further suggested studies. Since battery life and signal strength values must be greater than 1500 hours and 7mV/V respectively and the accuracy must be within 6μm it is necessary to see if the factor levels suggested in the S/N analysis yield these results within a desired 90% confidence interval.

All the other projects in this course were of the same level of scope and depth. All projects dealt with applications in various industries. Typically, the term project was a part of a larger project a student was involved with on the job.

Assessment, Discussion, and Conclusions

The assessment and student feedback from the course was managed by the University of Wisconsin Learning Innovations (UWLI) which was contracted by the university to provide support services. The course format, online course materials, and all other aspects of the course received ratings varying from 4.5 to 5, on a scale from 1 to 5 with 5 denoting excellent and 1 denoting poor, during 2001 through 2005. The instructor in contact with students not only through the web, but also via telephone when some critical issues with the term project had to be discussed. All the goals in each and every course assignment and term project were attained because the course required periodic progress reports on major course activities such as the paper review, software review and the term project. Based on the above feedback from students and instructor's experience, the course structure, administration, content, and the nature of major course work will not be changed in the near future. But the textbooks, assignments, and discussions may be updated periodically. In summary, the course has been very successful. Even though it is an elective course, there are students interested in enrolling in the course and that itself is an indication of the usefulness of the course. It may be interesting to note that some students who enrolled in this course had taken a course on the Design of Experiments taught by the same instructor.

The instructor was very pleased with the three different platforms (Prometheus, Blackboard, and Desire-to-Learn (D2L)) used for course management. The selection and use of the course management system for online courses at UW-Platteville was the responsibility of the University of Wisconsin Learning Innovations (UWLI) which was contracted by the university to provide support services for all online courses. The switch from one system to another was influenced by cost and budget considerations. The current course management, Desire-to-Learn (D2L), was developed with the assistance of the UW-System and has the lowest cost. The instructor is satisfied with this course management system because it has most of the features of Prometheus and Blackboard.

Feedback from students indicates that a major revision of the course will not be necessary. The addition of audio-visual course materials to lecture slides was not recommended by students as the course deals mostly with engineering, mathematics, and statistics. The telephone contact with students appreciated by all students and the course calendar includes at least two telephone contact with students.

The most attractive feature of the course is the weekly discussions on topics covered that week. The discussions are structured in such a way that students are required to apply the concepts and provide examples of potential applications in their field. These discussions cover diverse engineering and science disciplines. All discussions require student participation via specific questions and responses within a specific time period. So all students and the instructor learn about interesting applications of course materials from each other every semester. Students usually give permission to the instructor to use these applications in the course or use them for other educational purposes in the future. Instructor uses these applications to create new case studies, course assignments, and problems in tests. On the basis of the above feedback from students and experiences of the instructor the course has been extremely successful.