An applied approach to teaching a graduate-level research methods and design of experiments course

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ABSTRACT: In this article, the authors report their findings of effectively using an applied approach to teaching a research and design of experiments course at the graduate level. The Master of Science in Technology (MST) programme at Western Carolina University, Cullowhee, USA, accepts postgraduate students mainly with electrical and mechanical engineering technology backgrounds. Due to students' various mathematical foundations and different interests in research topics, traditional theory-oriented instruction methods for teaching statistical analysis and design of experiments are not effective for these students. The applied approach in this course combines statistical theories and the use of spreadsheets, such as Microsoft *Excel*®, to supplement instruction and requires students to apply the methods and tools in an applied research project. This approach has been implemented with demonstrated success with learning outcomes assessed by students' publications. The authors describe how this applied approach was implemented in this graduate level research methods course. Background objectives are presented, along with descriptions and examples of student research projects. Instructional methods, student performance and educational merits are also discussed.

INTRODUCTION

The Master of Science in Technology (MST) programme at Western Carolina University, Cullowhee, USA, accepts postgraduate students mainly with electrical and mechanical engineering technology backgrounds. In order to fulfil the programme's goal of nurturing technical professionals with strong experiential skills, applied scientific knowledge and engineering principles are focused on, rather than traditional engineering programmes that emphasise the theoretical aspects and fundamental research [1][2]. To achieve this goal, a *Research Methods and Design of Experiments* course (ET 603) is offered as a required core to the University's students. The main objective of this course is to introduce students to statistical analysis methods for applied research.

However, due to various mathematical backgrounds and different research interests among the student group, traditional theory-oriented instructional methods for teaching statistical analysis are not effective. Intuitively, a more effective method should combine theories, hands-on experiences, and applications of theory and skills. The applied approach centres on this concept, enhances students' theoretical understanding by using computer software packages and improves their application capabilities by applied research projects in the students' specialised fields. The following sections discuss the implementation of this applied approach in terms of theoretical backgrounds, computer tools applications and applied research projects.

THEORETICAL FOUNDATIONS

The importance of theoretical foundations for statistical analysis are stressed. Without adequate knowledge of fundamental laws and theory, this approach may give a false impression as to the ease of sound research designs, the appropriate selection of statistical methods and data analysis.

This virtual approach does not reflect a characterisation of sound research methods. Knowledge of basic laws, fundamental theory and statistical methods are essential for applying statistical methods and the design of experiments (DOE).

Traditionally, engineering and technology courses that focus on research methods have followed a classical approach to statistics by covering basic fundamentals and theoretical laws. The applied research DOE course followed a similar approach with an emphasis on traditional theory and logical sequence as shown in Table 1.

Table 1: Theoretical foundations for DOE.

Contents	Time(weeks)
Parametric Statistics	1
Sampling Methods	1
Hypothesis Testing and Statistical Procedures	1
T-Test Procedures and Limitations	1
Analysis of Variance (ANOVA)	2
Regression	2
Multiple Regression	3
Design of Experiments	4

This course is offered over a traditional 15-week semester. Fundamental statistical theories are introduced throughout the course. Unlike a traditional engineering course where derivations of mathematical equations are a main part of the course, the concepts behind these derivations and principles of statistical procedures are the focus.

With a solid understanding of the theoretical results, students are asked to logically apply the theories utilising computer tools like Microsoft *Excel*® or *Minitab*®. The reasoning and an example of using computer tools to enhance learning is described in the next section.

PRACTICAL SKILLS VIA COMPUTER TOOLS

Efficient use of computer software packages predominant in industry can significantly help students' applications of theories and better prepare students for their future career development. However, this common use has also contributed to differences between practicing engineers and technologists becoming more clouded [3]. Nonetheless, effective course design strategies implement instructional methodologies that affect multiple dimensions of learning [4]. Students who prefer abstract conceptualisation with concrete answers would likely benefit from solving theoretical problems in a more traditional manner, as described by Kolb [5]. Other students may achieve more positive learning outcomes through active experimentation using a hands-on approach. Because the University's programme emphasises practical knowledge, it is natural to utilise computer-based programs to promote a better understanding of statistical tools and procedures.

Statistical software packages enable students to perform computations more rapidly and efficiently, and statistical summaries generated by the software can be easily interpreted with only a modest knowledge of background theory. More sophisticated packages, such as *SPSS*® and *SAS*®, exist in the commercial world. However, Microsoft *Excel*® provides an excellent method of reinforcing learning through structured equations and a means for gaining immediate feedback, as suggested by Marsh [6]. Graphing and charting functions can also reinforce the basic understanding of systems through visual feedback. Therefore, Microsoft *Excel*® (with the Analysis Tool Pak Option) was chosen as the main statistical analysis tool in this case, and *Minitab*® was also utilised by some students for more complicated designs.

The implementation of the approach in this case has shown the following major benefits for students:

- Reinforced understanding of theories: students were required to develop spreadsheet solutions to applied problems using Microsoft *Excel*® corresponding to theoretical topics presented in class. Students were also required to write equations and structure spreadsheet development through a logical interactive approach;
- Developed working tools through modules: by means of interactive formula-based learning activities, students were able to build modules to perform certain statistical analysis tasks. By the end of the semester, students integrate these procedures by assembling modules developed as a working group to create a system tool for carrying out data analysis;
- Improved logical thinking and analysis capabilities: instead of utilising commercial software packages that provide relatively quick calculations to analyse variables and determine logical parameters for system components, students were required to develop structured equations based on the presented theory. Formulae entered in spreadsheet format required students to have a firm grasp of variables and relationships coupled with a logical input of equations to follow the analysis procedures. Further, calculations performed can be integrated with *canned* statistical procedures with relative ease by utilising spreadsheets. Through logical thinking and analysis, students learned how to identify appropriate statistical tools for selected research designs and, therefore, were able to develop custom spreadsheets related to the previous topics presented in class.

A classical example application was plotting the normal curve over a given data set in *Excel*®. The resulting graph is shown in Figure 1. In order to correctly generate the normal curve, students were required to understand the concepts of mean (μ), standard deviation (σ), and the probability density function for a normal distribution N(μ, σ), which is described by:

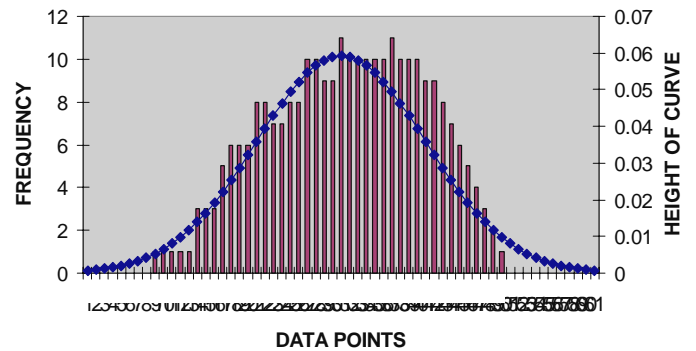$$f_X(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{1}$$

Figure 1: Normal curve over a given data set.

On the practical side, students mastered the skills of computing parameters in Microsoft *Excel*® using the corresponding equations and executing the *NORMDIST(x, mean, standard_dev, cumulative)* command to generate the data for the plot.

Additional benefits include the following:

- A better understanding of the difference between a cumulative distribution function and probability density function (probability mass function in the discrete case);
- Skills development in visually presenting the results.

APPLIED STUDENT PROJECTS

Besides homework and examinations, another form of assessing students' learning outcomes was the application of the theories and practical skills to applied research projects in one's specialised fields. The final reports were sent for peer reviews in the form of conference paper submissions. Reviewers' feedback was utilised to gauge students' quality of work, as well as provide reference for further course instructional improvements.

The procedures created in the worksheets were combined with statistical procedures within *Excel* for data analysis in completing the semester project requirements. Projects were required to be focused on process improvement and to be manageable within the scope of the semester. While not specifically required, most students focused on DOE by selecting two level factorial designs. The following two examples of applied student projects illustrate two applied research projects carried out by two students coming from different engineering disciplines.

The first project investigated the optimisation of setting up parameters for the HAAS© Z4 500 machine laser when it is used to cut a variety of flat-stock materials, including aluminium, steel and plastics [7]. The goal of this designed experiment was to investigate the optimal combination of power, frequency, feed rate and assist gas pressure that

produces high quality products. Table 2 shows the baseline settings of the independent variables. The DOE is a standard 2^4 factorial design and data were collected with two replications.

Table 2: Independent variable baseline settings.

Variables (A,B,C,D)			
A	B	C	D
Power (Watts)	Frequency (Hz)	Feed Rate (in/min)	Assist Gas Nitrogen (psi)
HI 500	HI 1000	HI 40	HI 120
LO 300	LO 900	LO 30	LO 90

Figure 2 shows the statistical analysis of the main effects. As can be observed from Figure 2, the greatest to the least significant effects were ordered as follows: power level, assist gas pressure, feed rate and frequency.
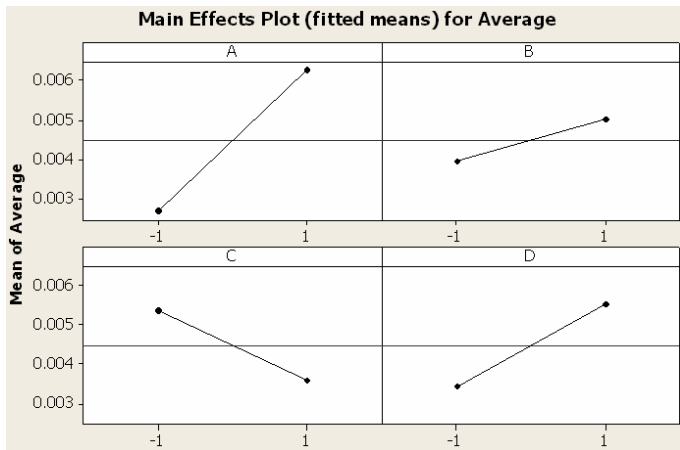

Figure 2: Main effects of the independent variables.

Figure 3 shows the second level interaction between the factors. As can be seen from Figure 3, even though some of the interactions were statistically significant, there was no interaction within the range of high and low baseline settings. If the plots were extended, they would show interaction. For the second level interaction of power and frequency, plots showed no interaction within the specified ranges. For the second level interaction between frequency and feed rate, there would be interaction if the plot was extended further. Second level interaction of feed rate and assist gas pressure interaction would also occur if the plots were extended further. The plot shows a definite interaction between frequency and assist gas pressure within the specified ranges.

The paper concluded with suggestions to optimise the operation of HAAS Z4 500 machine laser.

A second example investigated the effects of barrier materials and data rates on object detection using Ultra-Wideband (UWB) technology [8]. The design was a general two-factor factorial design with independent variables being barrier materials and transmission data rates. The treatments of barrier materials are wood and steel, simulating wood-framed residential homes and steel-structured buildings. The treatments of data rate were set at 600 kbps, 2.4 Mbps, 4.8 Mbps, and 9.6 Mbps. The goal was to investigate UWB signal penetration capability through these two different materials at various data rates.
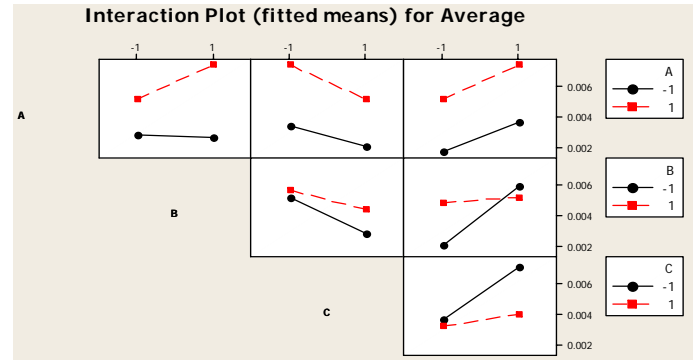

Figure 3: Second level interaction plots.

A control group was used for reference purposes. Four replications were conducted under each scenario and the run order was randomised. The response variable is Bit Error Rate (BER). The experiment design matrix is shown in Table 3. $y_{xx1 \sim xx4}$ represents four replications under scenario xx (for example: y_{214} means the 4th BER value with steel barrier at 600 kbps data rate.)

Table 3: The UWB experiment design matrix.

data rates / materials	600 kbps	1.2 Mbps	2.4 Mbps	9.6 Mbps
1 (wood)	$y_{111 \sim 114}$	$y_{121 \sim 124}$	$y_{131 \sim 134}$	$y_{141 \sim 144}$
2 (steel)	$y_{211 \sim 214}$	$y_{221 \sim 224}$	$y_{231 \sim 234}$	$y_{241 \sim 244}$

Table 4 shows the ANOVA results output by Microsoft *Excel*®. Interestingly, the effects of data rates on the penetration were not obvious, while the effects of barrier materials were significant. However, this does make sense for a communications system because, as long as received signal strength is sufficient, the BER is expected to be low regardless of the data rates. On the other hand, because different barrier materials attenuate the received signal strength in significantly different ways, the BER was also affected significantly.

Figure 4 shows the actual measured BER through experiments. It was clear that the experimental results strongly support the results obtained from the statistical analysis.

Table 4: Analysis of Variance (ANOVA) output by *Excel*.

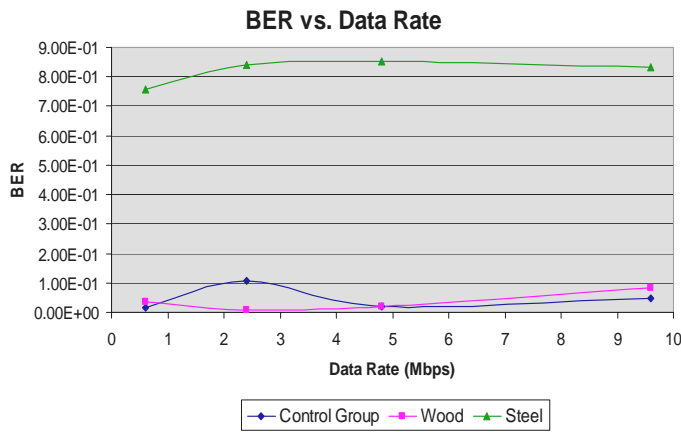| Source	SS	DF	MS	F	P Value	F-Crit
Average	4.371E+00	1	4.37E+00			
Material	6.479E+00	2	3.24E+00	428.877	7.790E-26	3.25945
Data rate	2.053E-02	3	6.84E-03	0.906	4.476E-01	2.86627
Interaction	3.647E-02	6	6.08E-03	0.805	5.729E-01	2.36375
Error	2.719E-01	36	7.55E-03			
Total	1.118E+01	47				

Figure 4: A comparison of experimental BER results.

EDUCATIONAL MERITS

The educational merits of this approach are obvious and significant. Firstly, students grasped the essence of the research methods that were intended to be conveyed by this course. This was evidenced by their capabilities of identifying a specific applied research topic and realising a design of experiment. This was further evidenced by the acceptances of their publications reviewed by the referees in their specialised fields. Secondly, students learnt hands-on analysis skills for statistical analysis. This was demonstrated by their capabilities of developing and utilising computer tools to analyse variables, as well as determining logical parameters for system analyses. Thirdly, students developed their abilities to apply methods and skills learnt to conduct applied research in their fields. As shown in the examples, students used methods learnt from this course and their knowledge in their respective fields to successfully solve issues in different engineering disciplines. As a result of this course, all five students in a single class were successful in having their papers accepted for publication and presentation.

Educational merit was also shown by the uniqueness of this approach. It is worth noting that these skills are not always explicitly taught in engineering curricula where the focus has been on content and analytical skills of specific engineering disciplines. Industry and the Accreditation Board for Engineering and Technology (ABET) nonetheless expect engineering graduates to have well developed computer skills [9].

The approach implemented in the ET 603 graduate course at Western Carolina University provides a logical and systematic method for building on theory and developing essential computer skills. Through immediate feedback, students can gain a better understanding of variables in equations and the impact of change with respect to independent variables to response variables. Further, as evidenced by student projects, the ability to apply theory and knowledge gained from lectures was demonstrated.

CONCLUSIONS AND FUTURE WORK

Positive results of the applied approach have been observed through students' feedback and performance, and integrated projects have provided a vehicle for transferring theoretical knowledge to a practical and systematic application. This practical approach has resulted in improved collaboration among students from various disciplines and has provided more continuity within the MST curriculum at Western Carolina University. Ongoing programme assessment will continue to provide feedback on the effectiveness of the methods implemented with the goal of continued class improvement.

REFERENCES

1. Kumar, R. and Plummer, M., Using contemporary tools to teach dynamics in engineering technology. *Inter. J. of Engng. Educ.*, 13, **6**, 407-411 (2000), http://fie.engrng.pitt.edu/fie2000/papers/1447.pdf
2. Grinberg, I., *Engineering Infrastructure Diagramming and Modeling*. Washington, DC: National Academy Press (1986).
3. Ball, A., Ferguson, C. and McDaniel, W., Using steam engines to teach parametric modeling and rapid prototyping. *Proc. ASEE - Southeastern Section Annual Conf. and Expo.* Tuscaloosa, USA (2006).
4. Wingo, O.G., Analysis of Learning Style Preferences in Adult Learners. Doctoral Dissertation, University of Florida (Dissertation Abstracts International, Publication no. AAI 9304072) (1992).
5. Kolb, D.A., *Experiential Learning*. Englewood Cliffs: Prentice-Hall (1984).
6. Marsh, B., Integrating spreadsheet templates and data analysis into fluid power instruction. *J. of Industrial Technology,* 16, **4**, (2000).
7. Godfrey, J.G., Ball, A.K. and Zhang, J.Z., On the optimization of setting up parameters for HAAS Z4 500 machine laser. *Inter. J. of Modern Engng. Conf.* (accepted), New York, USA (2006).
8. Heggen, S., Zhang, J.Z. and Ball, A.K., Effects barrier materials and data rates on object detection using Ultra-Wideband technology. *Inter. J. of Modern Engng. Conf.* (accepted), New York, USA (2006).
9. Accreditation Board for Engineering and Technology (ABET) Board of Directors, Criteria for Accrediting Engineering Technology Programmes. Baltimore: ABET (2003).