TEACHING EXPERIMENTAL DESIGN TO ENGINEERS: SOME EXPERIENCES AND ADVICE

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Designing and conducting experiments is an important aspect of engineering practice, with applications in both product and process design/development and manufacturing. This presentation focuses on the essential topics for an experimental design course and offers advice based on 30 years of experience in how to structure such a course so that is meaningful to an engineering-oriented audience. Some experiences from the course offered by the presenter at ASU are given.

TEACHING EXPERIMENTAL DESIGN

- IEE 572 Design of Engineering Experiments
- One-semester introductory graduate level course
- Offered both Fall & Spring semesters
- Audience is a mixed bag: industrial, electrical, chemical, civil, bio (and an occasional mechanical) engineers; material science, chemistry & physics (occasional), math and statistics students
- Sizable local industry participation
- Prerequisites are (theoretically) a first course in basic (or engineering) statistics
- Actual prerequisites consist of successfully answering three questions:
  - Are you familiar with the normal distribution?
  - Do you know how to compute the sample mean and standard deviation?
  - Have you been exposed to the *t*-test and the associated confidence interval?
- Course enrollment varies between 75 and 100+ students per semester
- One lecture section in a large hall; think freshman chemistry
- About 15% of a typical class consists of nom-matriculating students from local industry – these students are *important*
- About 50% of the students are required to take the course

COURSE SCHEDULE AND TOPICS (BASED ON TWO 75 MINUTE LECTURES PER WEEK)

- Introduction and course overview (1 lecture)
- A simple comparative experiment (the two-sample *t*-test) (2 lectures)
- Strategy of experimentation (1 lecture)
- Single-factor CRDs; ANOVA basics (3 lectures)
- The blocking principle (2 lectures)
- Introduction to factorials (fixed effects model only) (2 lectures)
- Two-level factorials (3 lectures)
- Blocking and confounding in factorials (2 lectures)
- Two level fractional factorials (5 lectures)
- Response surface methods (overview) (2 lectures)
- Experiments with random factors (3 lectures)
- Nested and split-plot designs (2 lectures)
- Two 75 minute term quizzes

COURSE MATERIALS

- Textbook: Montgomery, D.C. (2001). *Design and analysis of experiments* (5th edn.). New York: John Wiley & Sons.
- Student version of Design-Expert V6 and Student Solutions Manual bundled with text
- Website: www.wiley.com/college/montgomery
  - Course syllabus
  - Supplemental text material
  - Sample student projects
  - Power Point foils (instructor only)
- Instructor Resources CD/ROM

MORE ABOUT COURSE TOPICS

- Little emphasis on manual computations
  - Minitab, Design-Expert V6 – student version
  - Computer usage integrated into the lecture
- Model-oriented approach is key:
  - Engineers love and understand models
  - Focus on motivating problem-statistical design-underlying model
  - No experiment is truly successful unless the experimenter can build an empirical model that describes the results
- Choice of effects model, means model, regression model not really important

Analysis techniques: t-test, ANOVA, regression

- ANOVA presented in context of single-factor CRD
- Little emphasis on computations, multiple comparisons
- Both *P*-values and confidence intervals presented
- Residual analysis, model adequacy checking stressed
- Box-Cox procedure illustrated

Blocking

- "Block what you know about and can control, randomize the rest"
- Emphasis on the BCRD; Latin squares and multiple sources of nuisance variability briefly introduced
- Role of blocking in robustness studies discussed
- Uncontrollable nuisance factors and ANOCOVA mentioned, but not presented…students referred to text

Factorials

- Introduction based on two-factor fixed effects scenario
- General case treated quickly…emphasis on software
- Quantitative and qualitative factors stressed; response curves and surfaces introduced

Two-level designs

- Topic of huge importance to course participants
- Replicated and unreplicated designs, use of center points, analysis methods (normal probability plot, Lenth's method) covered in detail
- Blocking and confounding
- Fractional factorials, aliasing, design resolution, fold-over, Plackett-Burman designs
- Interpretation stressed; fitting the underlying model, response surfaces and contour plots

Response Surfaces

- Steepest ascent, analysis of a second-order response surface illustrated
- Central composite design emphasized
- "Lure" for a full-length course that follows

Experiments with Random Factors

- Single-factor CRD, point estimation of variance components

  - Two-factor factorial, random & mixed model, restricted & unrestricted model (using Minitab)
  - Example focuses on measurement systems capability study
  - Cornfield-Tukey EMS algorithm
- Nested and Split-Plot Designs
  - Two- and three-stage nested designs
  - Hard-to-change variables, two sources of error stressed in discussion of split-plots

TERM PROJECT

- *Important part of course; 25% of grade*
- *Team approach used*
- *Project is built around the seven-step approach:*
  - Problem definition
  - Identify design factors and their roles
  - Identify response variables
  - Select design
  - Conduct experiment
  - Analyze data
  - Conclusions and recommendations
- Two intermediate and one final report required
  - Oral presentations from selected teams
  - Previous project reports on text website

SAMPLE TERM PROJECTS

- "Automated Visual Inspection of Printed Circuit Boards"
- "Cupcake Height"
- "Is it Better to Chip or Putt?"
- "Optimization of Tungsten CVD Process"
- "Pavement Deformation"
- "Swimming"
- "Wine Storage"
- "Growing a Winter Lawn"

SUMMARY AND CONCLUDING REMARKS

- Course is broad in scope
- Topics reflect the difference between agricultural applications of DOX and industrial usage
- Not theory-oriented; this is not a mini-linear-models course
- Role of computer critical, used in nearly every lecture
- Project is extremely important
- Industrial participants welcomed; indeed, rather than being a nuisance they are actually very important