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 it 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 non-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

• 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