PLANNING EXPERIMENTS

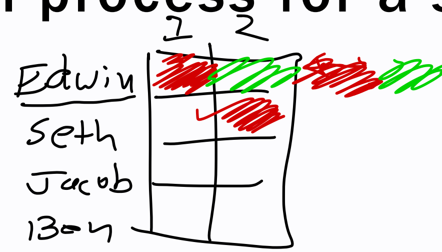
Chapters 1, 2

LEARNING OBJECTIVES

- Follow checklist for planning and conducting an experiment
- Explain the purpose of each step in checklist
- List the four principles of experimentation and their impact on the analysis of the design

PLANNING CHECKLIST

1. Define objectives
2. Define meaningful and measurable response
3. Diagram treatment application process for a single run
4. Identify experimental units
5. List sources of variation
6. Perform pilot runs
7. Choose experimental design (i.e. randomization)
8. Determine number of replicates required EUs
9. Describe method(s) for data analysis
10. Timetable and budget for resources to complete experiment



- Answers to one step may make you revisit previous steps

DEFINING OBJECTIVES

- "What questions are you hoping to answer?"
  - Broader than the data-specific questions
- What pairing of data and analysis methodology can answer this question?
  - Argue how the pairing can answer broad questions
- What will your analysis focus on?
  - Understand distribution of a single response?
  - Determine relationships between multiple variables?
  - Build a predictive model?
  - Determine causes of variation of a response?
  - Find conditions that optimize response?

DEFINING MEANINGFUL RESPONSE

- Characteristic of the EUs can be reliably measured and recorded after each run
- Represent changes caused by treatment application
- Determine how large an effect should be for treatment differences to be practically meaningful
- Single measurement or repeated measurements?

obs units differ from Exp unit

- Measurement variability?

DIAGRAM TREATMENT APPLICATION PROCESS

- List out thorough explanation about how a treatment will be applied for a given run
- Leads to repeatable and reproducible experimental protocol
- Anticipate potential difficulties or inconsistencies
- Helps determine the EUs, but may not completely answer the question

IDENTIFY EXPERIMENTAL UNITS

- What exactly are you applying each treatment factor level to?

- Some possibilities
  - Animal
  - Human subject
  - Raw material for some processing operation
  - Conditions that exist at a point in time (most abstract)

- May have multiple descriptions, pick the one that is mostly influenced by the treatment factors

LIST SOURCES OF VARIATION

(what can influence our outcome?)

- Consider variables that are known to or may significantly influence the response

- Response is measured from OUs taken from EUs
  - Which variables affect EUs? Influence response?
  - How are we measuring response? Reliable?

- Specify as quantitative or categorical
- Highlight the treatment factor(s)
- Variables that are influential but uncontrollable are lurking variables (can these be measured?)
- Are variables held constant? What level and why?

PERFORM PILOT RUNS

- Try out the experimental protocol on a few EUs
- Verify or determine the following:
  - Can control and vary factors selected
  - Response can be reliably measured
  - Treatment application process is repeatable
  - Rough estimate of variation
- May need to revisit previous steps after this part
- Not always possible but always beneficial when done

CHOOSE EXPERIMENTAL DESIGN

- Consistent with objectives and prevents uncontrollable changes in lurking variables from biasing effects
- Specifically states which treatment factor levels will be studied and how they are assigned to EUs
- This course surveys many designs depending on objectives and identified nuisance factors
- Each design has a proscribed randomization method of assigning treatment conditions to EUs

DETERMINE NUMBER OF REPLICATES REQUIRED

- How many replicates for each treatment condition?
- Requires an expected variance and effect size of a practical difference
- Aims to give researcher a high probability of detecting the desired effect size
- Based on statistical model and analysis procedure

DESCRIBE METHODS OF ANALYSIS

- Write statistical model and clearly explain what each parameter represents
  - One-way ANOVA
  - Multi-way ANOVA
  - Regression models
  - General linear model (both ANOVA and regression)
- Inference methods: hypothesis testing? Confidence intervals? Post-hoc analysis?
  - Reference how these answer stated objectives
- Anticipate difficulties and back-up analyses

TIME TABLE AND BUDGET

- Experiments take time and have a lot of moving parts
- Having a schedule keeps the experiment moving forward and improves the chances of the research being completed on time
- Outline budget for expenses and resources available
- Make sure the proposed design is in line with the budget, otherwise revisit the design

PAPER AIRPLANE EXPERIMENT

- Two competing paper airplane designs and you want to determine which design is best
- Recruit human subjects to build and throw airplanes

1. Define objectives
2. Define meaningful and measurable response
3. Diagram treatment application process
4. Identify experimental units
5. List sources of variation

KEY PRINCIPLES OF DESIGN

- An experimental design specifies the assignment and application of treatments to a set of EUs
  - A “good” experimental design will reduce bias and minimize variance of the truth we want to estimate

- The following four principles are basic requirements for a successful experiment
  - Representativeness
  - Replication of treatments
  - Randomization
  - Local error control

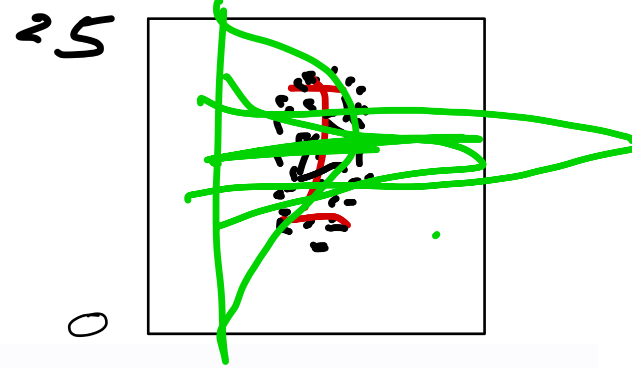
REPRESENTATIVENESS

- Applies to all studies, not just experiments
- EUs should be representative of the population we want to make inferences from

- Mouse smoking experiment: extend results to humans?

- Reducing EU-to-EU variability reduces experimental error, but at the cost of representativeness
- Design techniques exist that broaden pool of EU’s without increasing response variation

REPLICATION



- In order to be certain of a treatment's effect, it must be observed repeatedly with independent applications across different EUs

- Increasing replication can lead to
  - Better estimate of variation — standard deviation
    vs.
    standard error $\frac{\sigma^2}{n}$
  - Increased precision of treatment comparisons
  - Assurance against aberrant results due to random chance
  - Increase in cost

- Replication does not decrease variation!
  - Including more EUs, which are less likely to be similar

RANDOMIZATION

- Given fixed number of replications for each treatment, determine allowable assignments of treatments to EUs (depends on design)

- A design has been properly randomized when all allowable assignments are equally likely to be used
- Haphazard assignment does not equal proper randomization!

- Not enough to say that each treatment has the same chance of being assigned to any EU

RANDOMIZATION

- Foundation for causal inference, since we can actively reduce the possibility of bias
- Randomization also generates its own statistical analysis with minimal assumptions
- You will be asked to describe the randomization procedure for every design we learn about
  - I will grade the procedure as if I know little about statistics and am following your instructions

LOCAL ERROR CONTROL

- Techniques to minimize variation
  - "Local" because it is specific to the one experiment
- Some examples
  - Controlling the experiment environment (done in labs)
  - Choosing experimental units to be as similar as possible
  - Minimize treatment replication error

- Red-highlighted techniques above could sacrifice representativeness

- Employ design techniques to reduce variation without sacrificing representativeness

LOCAL ERROR CONTROL
BLOCKING

- Consider EUs and identify nuisance factors that could influence response
  - Inherent property of EUs (e.g. sex, weight, manufacturer)
  - Environmental influences (e.g. operator, wind, time)

- Block: group of EUs with similar nuisance levels
- Each block should receive all possible treatments when possible
  - Smoking study design 2

- Comparing treatments within each block and “pooling” results reduces experimental error

LOCAL ERROR CONTROL
ANALYSIS OF COVARIANCE

- Can only block if we know about nuisance factors prior to randomization
  - What to do if we can only measure nuisance immediately before treatment application?
- Propose statistical model to "adjust" for covarying effects of the nuisance factors on response
  - Block designs require specific statistical models, too, but are different because they have their own randomization scheme
- Success depends on accuracy of statistical model

ETHICAL CONSIDERATIONS

- Obviously, ethical considerations need to be considered when designing an experiment
- If experimenting on living beings you need to first get Internal Review Board (IRB) approval
- Clever experimental designs can maximize information using minimal resources and reduce impact on environment and animals

- Ethical considerations/constraints can often lead to interesting design problems
  - Crossover designs
  - Clinical trials

LEARNING OBJECTIVES REVIEW

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