What my experiment died from: common sources of variation

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Designing Experiments and Studies

“The statistician... makes his most valuable contribution simply by persuading the investigator to explain why he wishes to do the experiment” - Cox (1950)

- Successful statisticians are able to:
  - Understand the underlying science of a problem at some level
  - Extract the pertinent information
  - Incorporate into the design and analysis

- Issues arise when a statistician lacks DOX training, and/or an ability to effectively communicate

- All statisticians are taught to analyze data but not always to design experiments (DOX)

- Analysis-only training rarely emphasizes the importance of understanding how data were generated/colllected
  - DOX and survey sampling highlight how different collection procedures lead to different statistical models
Learning from Statisticians

R. A. Fisher

George Box

Gertrude Cox
Communicating with Non-Statisticians

“...if we aspire to be effective in our collaborations with scientists ... we need to act like scientists” - Vining (2013)

• Statisticians wish their clients were more familiar with statistics
• **Clients wish statisticians were more familiar with their area**

• FTC sessions about training data analysts in both technical and communication skills

• Technical skills are only useful if you can effectively communicate ideas and results with your collaborators
Learning from more Consulting Experts

• Experts have been discussing improving collaboration for years

• Bliss (1969): avoid answering any questions on statistics until the scientific background of the problem is ascertained

• Zahn and Isenberg (1983) first part of session is identification of relevant aspects of the problem.
  • Emphasize that statistician should frequently reflect back to the client his/her understanding of the problem

• Hunter (1981): “Be curious. Ask a lot of questions.”

• Coleman and Montgomery (1993): article helps “bridge the gap” between statisticians and engineers in collaboration
Thinking like Scientists

• Ideas presented aren’t intuitive; no one is born communicating well

• Are all experiments doomed to die an untimely death while we wait to gain collaborative experience?

• It is one thing to tell people to ask questions and think like a scientist, it is another to know how to implement that

• Ask science questions; evaluate like a statistician

• Memorable examples might be the key to communication
Experimental Units and Treatments

• **Treatments**: factor(s) of interest manipulated by experimenter

• **Experimental units (EU)**: what we apply the treatments to
  - Observational units (OU): part of the EUs measured if we have subsampling

• The treatment application process (which people often just call treatment) is ideally a major source of variation

• **All other major sources of variation are realized through the experimental units and the measurement process**
Common Types of Sources of Variation

• DOX textbooks say to first list out all major sources of variation but give little advice on how to figure them out
  • Hinkelman and Kempthorne (2008) discuss this at length and provide examples in their textbook

• Students/professionals learn these indirectly from experience or classroom examples

• Campbell and Stanley (1963) detail these sources of variation for education research but concepts still apply

• Framed in terms of internal and external validity
Internal and External Validity

• **Internal Validity:** how well an experiment was conducted
  • For the units in this experiment, can observed changes – or lack of changes – be attributed to the treatment?

• **External Validity:** how well the conclusions from one experiment apply to another
  • Is the experiment reproducible?
  • Can the results be generalized outside of an experimental setting?
Threats to Internal Validity

• *Treatment Replication Error:* inability to perfectly replicate a treatment application
  • Moral: All EUs should be treat(ment)-ed equally

• *State Error:* EU changes during the experiment in way unrelated to the treatment
  • Moral: Nothing is permanent but (EU) change
Threats to Internal Validity

• *Selection/Sampling Error*: characteristics in one sample of EUs/OUs will differ from another sample, both may differ from population
  • Moral: A sample is like a box of chocolates: you never know what you’re going to get

• *Measurement Error*
  • Moral: Do your measurements measure up?
Threats to Internal Validity

• *Dropout*
  • Moral: Don’t count your EUs before they hatch (or before you’ve taken measurements)

• *Selection bias*: sample collected in a way that misrepresents population
  • Moral: To thine own population be true
Threats to External Validity

• *Testing*: awareness of testing may impact outcome (Internal Validity)

• *Reactivity*: results occurred only as an effect of studying the situation (External Validity)
  - Moral: You are what you test

• *Experimenter bias*
  - Moral: You might be your own worst enemy
Threats to External Validity

• *Multiple-treatment interference (crossover designs):* when applying multiple treatments to the same EU, carryover effects may impact generalizability
  • Moral: If two treatments diverge in the woods, test them both

• *Situational Error:* differences between experiments in treatment conditions, time, location, etc.
  • Moral: It is our differences that divide our results.
Modelling

“All models are wrong; some are useful” – Box (1979)

- Data-driven models
  - Data-driven models might be prone to overfitting
  - Consider science-driven models instead

- Useful to have same statistician see experiment from design phase to inference

- If your experiment has died, the modelling step isn’t going to save it
Beyond Morals

“My revered teacher Prof. Whitehead of Cambridge used to say...: ‘The essence of applied mathematics is to know what to ignore’”
- Fisher (1938)

• Learn to critique statistical models to improve understanding of when a model is and isn’t appropriate

• For every experiment, explain how the analysis from a given statistical model answers the research question(s)

• Encourage statisticians to collaborate outside the discipline and learn how to ask other people about their work
  • Group projects in interdisciplinary statistics courses

• Must be reiterated throughout undergraduate, graduate, and early-career programs
Conclusions

• **How to decrease experiment mortality rate:**

• DOX understanding and vocabulary

• A willingness to think outside the box (as Box did)

• An ability to practice communication, just as we practice our technical skills

• Using short, non-technical examples to illustrate potential issues

• **Let’s keep our experiments alive!**

“To consult the statistician after an experiment is finished is often merely to ask him to conduct a post mortem examination. He can perhaps say what the experiment died of.” - Fisher (1938)
References


• Cox, G. (1950), Speech delivered to the Department of Agriculture.


Thank you!