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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

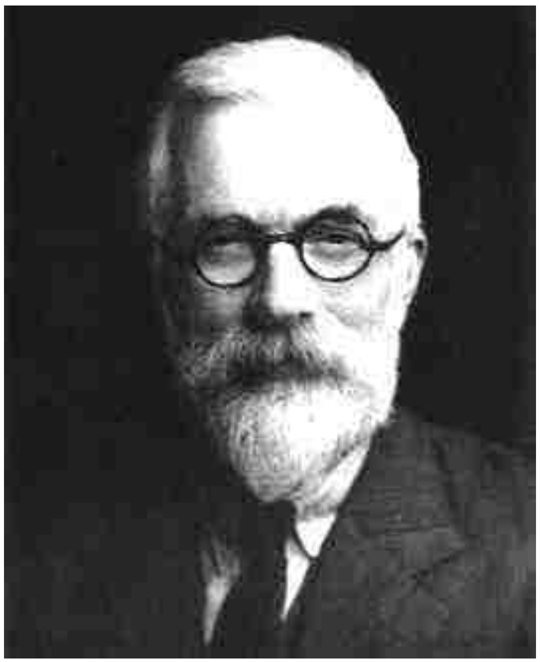
- Issues arise when a statistician lacks DOX training, and/or an ability to effectively communicate

- 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/collected
  - 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)

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Thank you!