Teaching the principles of design of experiments

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Writing a protocol

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- Proposed statistical analysis

A pig experiment

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Calling it y_{231}

- ignores the pigs;
- encourages non-blindness;
- encourages operation by treatment instead of by litter.

Pigs revisited

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- What are the observational units? 12 piglets $\times$ 8 weeks
- What measurements are to be recorded? The weight of each piglet in kilograms, in the early afternoon of the Tuesday closest to its n-th week birthday, for $n = 1, \ldots, 8$.

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- Plan See above
- Proposed statistical analysis For each week, do an analysis of variance incorporating litters and feeds, giving means and standard errors of differences for the feeds.

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If the answer is something vague like ‘to investigate new varieties of sunflower’ or ‘to find out about the nutritional effects of margarine’, there may be a perfectly worthwhile exploratory experiment to be done but a statistician is unlikely to be able to help you.

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Usually it is better to state a specific question that is to be answered, such as

- to estimate how much better drug A is than drug B in reducing inflammation (of course, the two drugs would need to named more precisely)
- to test the hypothesis that there is no effective difference between organic and inorganic nitrogen as a source of fertilizer
- to fit a model for how much sucrose is absorbed at different distances from the surface of the liver.

What are the treatments?

Give a precise description of the treatments that you intend to apply to the experimental units. Give complete technical details, such as

5mg of ciprofloxacin 4 hours after contact.

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In an experiement to compare two new pesticides, we should ask the scientist if he just wants to compare the two new pestcides with each other or if he wants to compare them both with the effect of doing nothing. If the latter then there is a third treatment, ‘do nothing’, which is often called control. You should always ask if a control is needed.

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increasing doses of a quantitative factor However, factors such as the amount of fertilizer are indeed quantitative, but not really on a continuous scale, because the farmer will use a whole number of bags of fertilizer.

Factorial treatments

Twelve treatments are all combinations of:

factor	levels
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\begin{tikzcd}[column sep=small]
 & E(Y_\omega) = \tau_{C(\omega),F(\omega)} \arrow[d, dash] & \\
 & E(Y_\omega) = \lambda_{C(\omega)} + \mu_{F(\omega)} \arrow[dl, dash] \arrow[dr, dash] & \\
E(Y_\omega) = \lambda_{C(\omega)} \arrow[dr, dash] & & E(Y_\omega) = \mu_{F(\omega)} \arrow[dl, dash] \\
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←Interaction

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Factorial treatments plus control

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	0	80	160	240
None	$\surd$			
Early		$\surd$	$\surd$	$\surd$
Late		$\surd$	$\surd$	$\surd$

Methods

This is where you describe exactly how you apply the treatments to the experimental units, and what you do from then on until all measurements have been taken.

There should be sufficient detail for other scientists to replicate your work.

What are the experimental units?

The experimental units are what you apply the treatments to.
Describe them carefully. It is helpful to note how many there are.
For example (the dots denote missing technical details)

- 20 male Wistar rats . . .
- 3 parts of the orchard (which parts? how separated? what area?)
- 12 student volunteers each used every day for 5 days
  (this is 60 experimental units if treatments can be changed daily)
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How should the experimental units be chosen? Should they be as alike as possible or be representative? If they are unalike then any variation between the experimental units may swamp any differences between the treatments that you are trying to find, especially in a small experiment. If they are not representative, you cannot extrapolate your conclusions.

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Of course, you need to know what you are going to measure before you can say what objects you are going to measure, so fill in the 'What measurements are to be recorded?' box at the same time as this one.

On the data sheet, there is usually one row for each observational unit.

It is helpful to state the number of observational units, especially if they are not the same as the experimental units.

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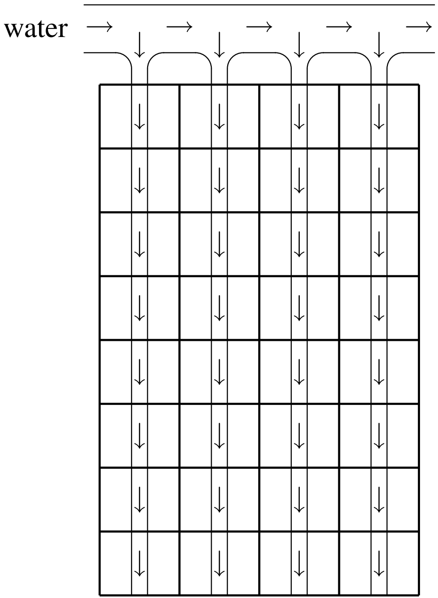
Irrigation channels in a rice experiment



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Do not make 'neat' copies: you are likely to introduce errors.

The danger of makeing intermediate calculations

In an experiment on leafstripe disease on barley, one measurement was the percentage of disease on each plot. The agronomist took a random sample of ten quadrats in each plot, inspected 100 tillers (sideshoots) in each quadrat to see how many were infected, and averaged the ten numbers. Only the average was recorded in the 'official' data. I saw a collection of pieces of paper like this.

Plot 8	6
	0
	7
	3
	6
	0
	4
	5
	6
	4
Average	4.1

Plot 23	0
	0
	0
	0
	0
	0
	0
	28
	0
	0
Average	28

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In really complicated cases
(such as incomplete-block designs, or confounded factorial designs),
you need to write out the complete systematic design.

Justification for the design: replication

For a simple design, you need to justify the amount of replication.

- If there is too much replication then the experiment may waste time and money. If animals are to be sacrificed, it is unethical to use too many.

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- If there is too much replication then the experiment may waste time and money. If animals are to be sacrificed, it is unethical to use too many.
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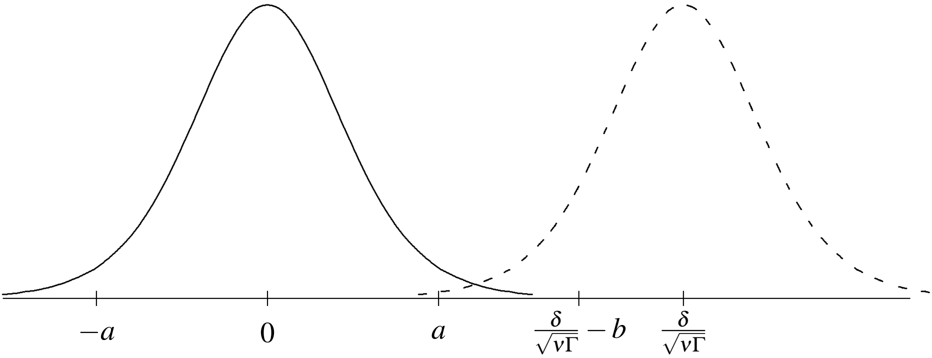
- Watch out for false replication.

Replication for power



Solid curve defines the interval $[-a, a]$ used for the hypothesis test; dashed curve gives the probability density function of the test statistic $\Delta/\sqrt{\nu\Gamma}$ if the real difference is δ

False replication

Three pesticides were compared for their side-effects on ladybirds.

A field was divided into three areas and one pesticide applied to each area. Ladybirds were counted on three samples from each area.

$$\begin{aligned} \text{Treatments} &= ? \\ \text{Experimental units} &= ? \\ \text{Obersvational units} &= ? \\ \text{Replication} &= ? \end{aligned}$$

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$$\begin{aligned} \text{Treatments} &= \text{3 pesticides} \\ \text{Experimental units} &= \text{3 areas} \\ \text{Obersvational units} &= \text{9 samples} \\ \text{Replication} &= \; ? \end{aligned}$$

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Treatments	=	3 pesticides
Experimental units	=	3 areas
Obersvational units	=	9 samples
Replication	=	1

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- Choice of systematic design

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- systematic bias (for example, doing all the tests on treatment A in January then all the tests on treatment B in March)
- selection bias (for example, choosing the most healthy patients for the treatment that you are trying to prove is best)
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How do we randomize? Write down a systematic plan. Then choose a random permutation (from a computer, or shuffle a pack of cards) and apply it to the systematic plan.

Explain how this was done.

Plan

This gives the exact details of which coded treatment is allocated to which experimental unit.

Litter	1	1	1	1	2	2	2	2	3	3	3	3
Pig	1	2	3	4	5	6	7	8	9	10	11	12
Feed	3	1	1	2	3	1	3	2	1	2	3	2

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Of course, you may end up doing a different analysis from the one you proposed. This can happen if something goes wrong during the experiment, or if further information comes to light.