

BIOL1051C Labs

Lab 03— Scientific design.

We only can learn from our mistakes. Karl Popper

Introduction:

The purpose of this lab is to wrap up our learning of science and its method with a discussion of scientific design. We will do so by reading some general rules about scientific design in biology (originally, ecology, but they are applicable), and then work on three experiments with different designs. Please keep in mind that the number of possible scientific experimental designs is essentially infinite, but that these designs are based on a relatively small number of design rules.

Lab 03

Scientific Design

10¹ 8 simple rules for experimental design in biology (from the next text file in Modules)

1. Begin by identifying a hypothesis for the topic you are interested in. Testable predictions generated will allow you to formulate a hypothesis. The hypothesis is an explanation of how you think a system works based on observation. The hypothesis will be either accepted or rejected based on the data collected.
2. Define parameters for the experiment by being clear and concise in your wording. By clearly defining terms, you can focus in on experimental methods and avoid ambiguity. This ensures that the results will be more accurate and there will be less flexibility in the experimental design, again increasing accuracy (Hurlbert, 1984).
3. Decide if you would like to perform a mensurative or manipulative experiment. A mensurative experiment involves making measurements at different times or in different areas. A manipulative experiment involves physically altering a treatment group, and thus always has two or more treatments (Hurlbert, 1984).
4. Choose an appropriate sample size that is fitting for the results you wish to obtain. Generally, a smaller sample size produces results that are inaccurate for generalization. A smaller sample size will also produce a smaller effect size measure, which is the efficacy of the treatment, and thus should be avoided (Ionnidis, 2005).
5. Introduce a control group. In biology, systems tend to exhibit temporal change, which could be an influencing third variable. In order to isolate any changes to the experimental treatment alone, a control is necessary.
6. Randomize assignment. By randomizing sample units to different treatment groups, experimenter bias is avoided. Randomization is a critical facet of the experimental design as it intersperses the samples being tested (Hurlbert, 1984).
7. Replicate! The number of replicates necessary will vary with design, however it ensures precision in experiments (Oksanen, 2001).
8. Ensure that samples are dispersed in space or time to avoid pseudoreplication. This ensures that replicates are statistically independent. Often, experimenters will make inferences based on the data collected and quantify samples from the same unit as independent, but in reality the samples come from the same unit, thus it is not a genuine replication (Oksanen, 2001).

¹ Rules 9 and 10 were stricken because they depend on statistical knowledge provided outside of this course.

9. Use linear regression-based analysis first, before introducing analysis of variance (ANOVA). Linear regression is more powerful to analyze obtained data, and indicates how dependent variables change with the independent variable (Cottingham, 2005).
10. Refrain from deducing results based on p value alone. The p value is indicative of confidence interval in statistics, however it fails to indicate how a system actually changes. Effect size measures are more meaningful in ecology, and thus should be given more weight in findings (Stern and Smith, 2001).

Three examples of scientific design

The following are data from three styles of experimental designs. The first set is a hydration experiment (Table I): the animals went through varying degrees of activity and the amount of water drunk was measured for an hour post-exercise.

Table I— Results for hydration experiments. One animal exercised intensely during 120 minutes on the yard (animal a), whereas the other stayed at home and only showed light movement (animal b). The experiment was repeated during 10 days. The amount of water drunk during an hour immediately after exercise was recorded in liters (L).

day	animal a	animal b
1	0.9	0.5
2	1.8	0.1
3	1.6	0.1
4	0.8	0.0
5	1.2	0.5
6	1.6	1.0
7	0.9	0.3
8	1.7	0.1
9	2.0	0.5
10	1.8	0.2

The second set is the feeding experiment (Table II) — a variant of the previous experiment: the animals went through varying degrees of activity and the amount of food eaten was measured for an hour post exercise. Higher mean food consumed ($\bar{x}$) will show more consumption, whereas lower will show less consumption. Standard deviations (s) will help understand how consistent the results are (the lower the s , the more consistent the results).

The hydration and feeding experiments (Tables I and II) are designed for mean ($\bar{x}$) comparisons between both groups. Higher $\bar{x}$ will show more consumption, whereas lower will show less consumption. Standard deviations (s) will help understand how consistent the results are.

Table II— Results for feeding experiments. One animal exercised intensely during 120 minutes on the yard (animal a), whereas the other stayed at home and only showed light movement (animal b). The experiment was repeated during 10 days. The amount of food eaten during an hour immediately after exercise was recorded in grams (g).

day	animal a	animal b
1	0.8	0.3
2	0.4	0.0
3	0.2	0.0
4	0.3	0.1
5	0.4	0.2
6	0.2	0.6
7	0.1	0.0
8	0.3	0.1
9	0.3	0.2
10	0.6	0.1

The third set is the classroom-side segregation by sex experiment (Table III). A number of classrooms was chosen and virtually divided in left and right halves. The number of females and males present on each side was recorded midway through the lecture. The number of females and males on the left side was subtracted from the number of females and males on the right side. The absolute value (*modulus*) of the difference was calculated for both females and males. In this experiment (Table III), both female and male $\bar{x}$ must be compared with 0. The reason for this is that if students of both sexes distributed themselves randomly in the classroom, then the number on one side subtracted from the other would be 0. If there were no classroom-side preference, then the number of students of either sex on both sides would be the same. A departure of $\bar{x}$ from 0 shows a side preference. Here too, standard deviations (*s*) will help understand how consistent the results are.

TableIII— Results for classroom-side segregation by sex observations. Each classroom observed was virtually divided in left and right halves. The number of females and males on the left side was subtracted from the number of females and males on the right side. The absolute value (modulus) of the difference is presented below. The experiment was repeated during 10 days. The numbers represent students.

day	females	males
1	0	1
2	0	3
3	2	5
4	0	4
5	0	2
6	1	3
7	0	3
8	1	5
9	0	7
10	0	1

Self-test:

1. To answer the following questions, you will need to calculate the means ($\bar{x}$) and standard deviations (s) for all results.
2. What can one say about the hydration experiment (Table I)? Is there an association between exercise levels and water drinking? Explain.
3. What can one say about the feeding experiment (Table II)? Is there an association between exercise levels and feeding? Explain.
4. What can one say about the classroom-side segregation by sex experiment (Table III)? Is there classroom-side segregation by sex? Do both sexes segregate? How consistent is the segregation (or absence thereof)? Explain.

Calculations

As before to calculate these $\bar{x}$ and s , you should go to the webpage below, change Population to Sample, and follow instructions about data entry. Use the data from Table I, II, and III.

<https://www.calculator.net/standard-deviation-calculator.html>

Literature cited:

Cottingham KL, Lennon JT, Brown BL. 2005. Knowing when to draw the line: designing more informative ecological experiments. *Front Ecol Environ*. 3(3):145-152.

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Sterne JAC, Smith GD. 2001. Sifting the evidence—what's wrong with significance tests? *BMJ*. 322(7280):226-231.