Vocational Aqualabs

TRAINING

Vocational Aqualabs – Vocational Generic Skills For Researchers

Experimental Design
Unit 1

University of Stirling

General introduction

As scientists we have all had problems to solve as part of our research. The standard method for scientist to do this is to decide on a hypothesis or a predetermined outcome and test it. This is known as the scientific process. However, to do this we must ensure both the precision and accuracy of our outcome, and to do this we use experiments which have to be carefully designed and use appropriate statistics to test the outcomes of the experiment. Because these two processes are intimately involved we need to ensure that the design of the experiment is correct to test our hypothesis and the statistics used correct for the particular experimental design. This short course is about making sure that you use correct and appropriate experimental designs to test hypotheses you generate as part of your research.

The course will introduce the student to the fundamentals of designing scientific experiments in both laboratory and the field. The course will include fundamental thought in the philosophy of science, the collection and the use of data, and fundamentals of statistical analysis and the analytical process.

So why should we bother using statistics as part of our experimental design and proof of hypothesis? Well, statistical methods can be used to help us summarise or describe data that we have collected – this is called **descriptive statistics**. When we begin to look more closely at the data and study them, we may see that there are patterns within the data that then allow us to explain the results of our experiments. From here we can then draw inferences of what is going on in the data / experiment under study. This is called **inferential statistics**. Both descriptive and inferential statistics can be considered to form part of **applied statistics** (i.e. the use of statistics and statistical theory in real-life situations).

The basics of Experimental Design and Analysis

As scientists, both natural and social, at some time or another we will run experiments or carry out observations in order to test one or more hypotheses and then test them by analysing the data we collect. Unfortunately, for many scientists, a standard experimental protocol is often this (Figure 1):

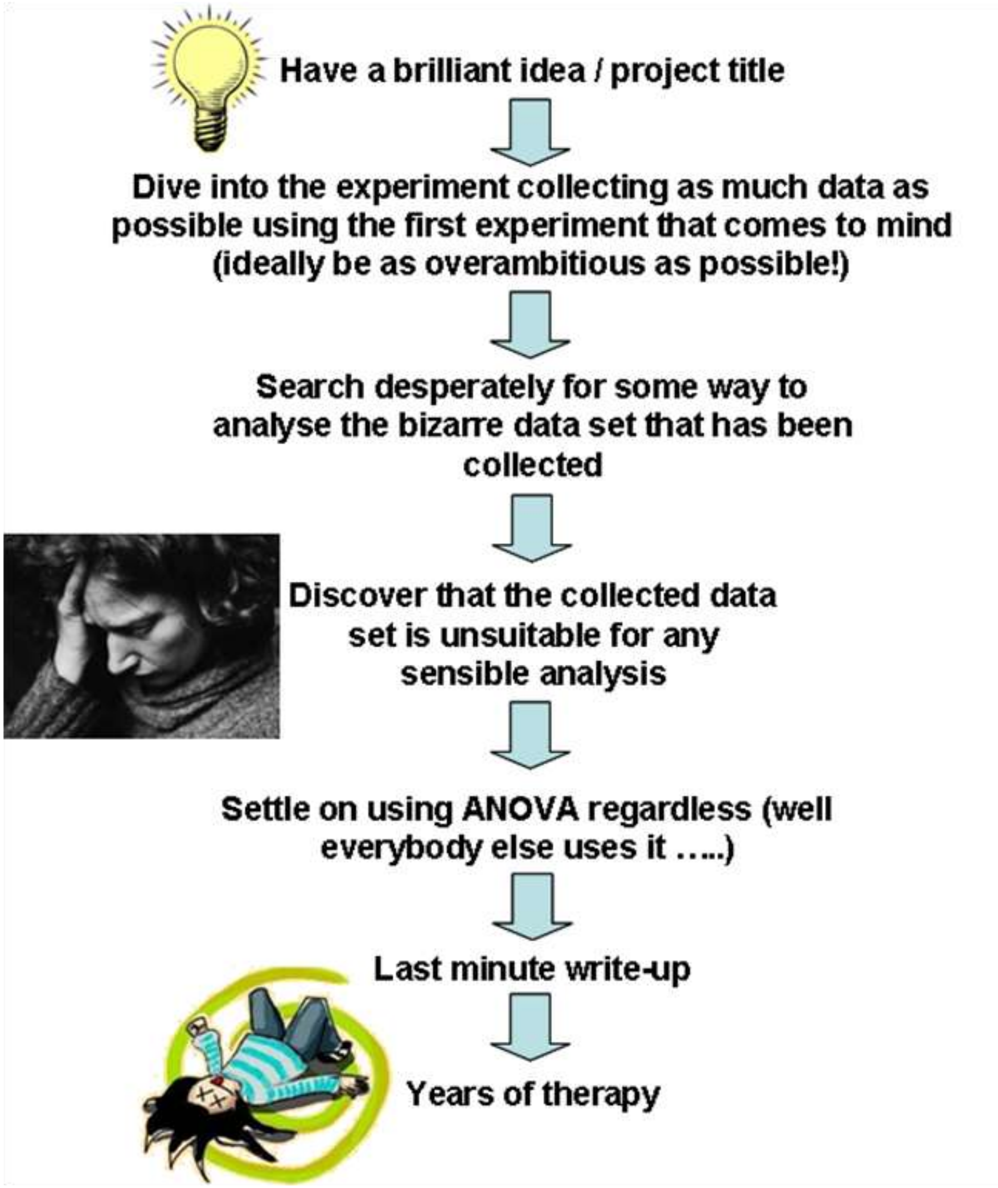


Figure 1: The "standard" experimental protocol (Images used from various sites on the internet).

In the diagram above some of the common mistakes made by the overambitious experimenter can include:

- the lack of replicates in their experimental design (i.e. commonly only one tank/pond per trial is used where ideally three or more per group is required),
- trying to measure too many variables
- too few observations or data points for each sampling point.

So what should have been done? Well the Figure 2 shows the thought processes and steps involved in a well-designed experiment.

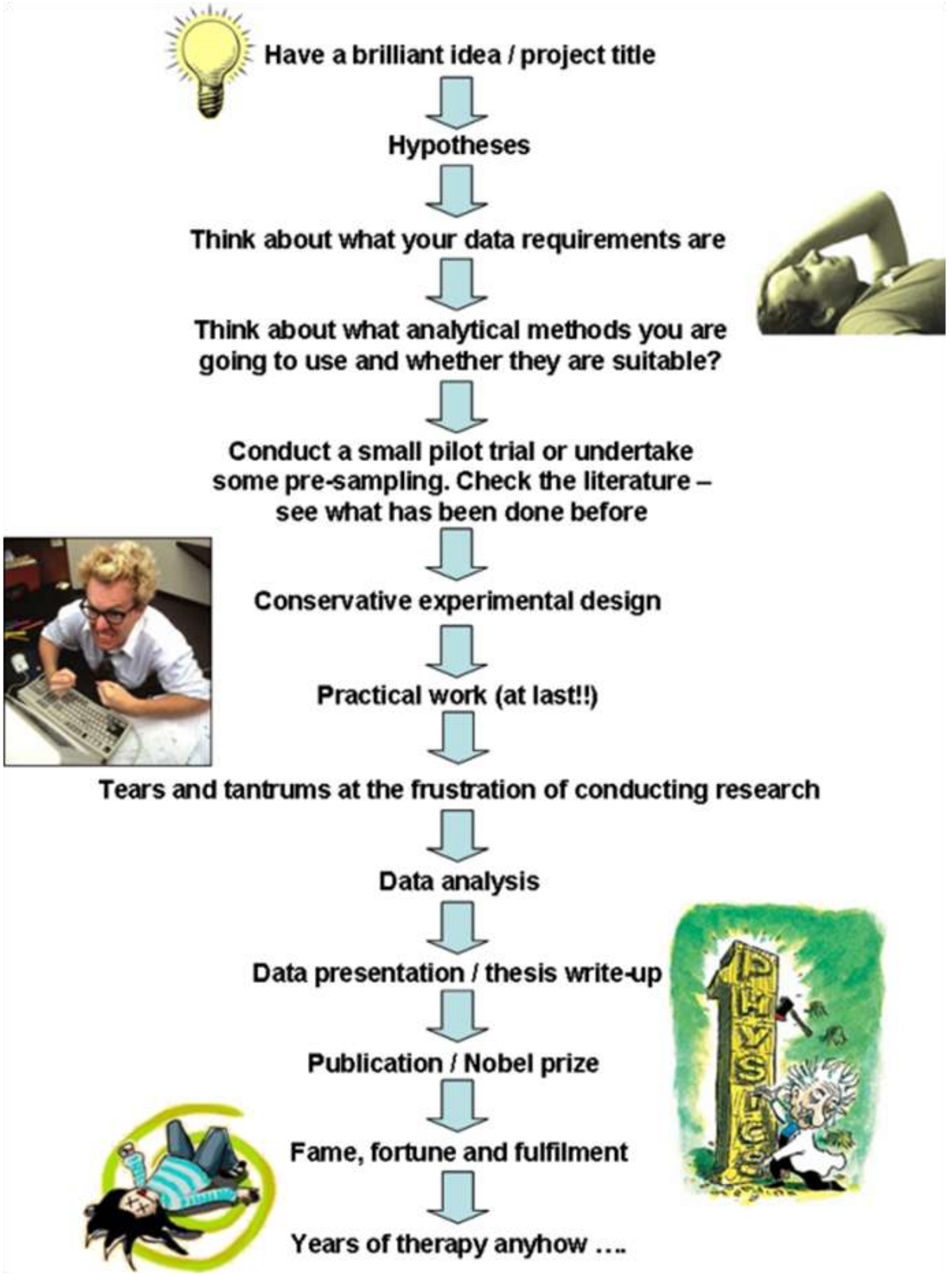


Figure 2: The improved experimental protocol. (Images used from various sites on the internet).

As you can see from this diagram by spending some time at the start of your experimentation, carefully thinking and planning your experiment may allow you to collect the quality data you need to answer the questions you set out to look at. The alternative to this of course is that you rush in, collect poor data and as a consequence most likely have to repeat your experiment and spend more money in doing so, lose your hair at all the additional stress and have your neighbours goats laugh at you.

Of course one reason why we undertake experimentation is to collect the data we need to support a theory we have and turn the idea into theory supported by data supported by statistical testing. Let's have a very quick look at the steps involved in doing this (Figure 3).

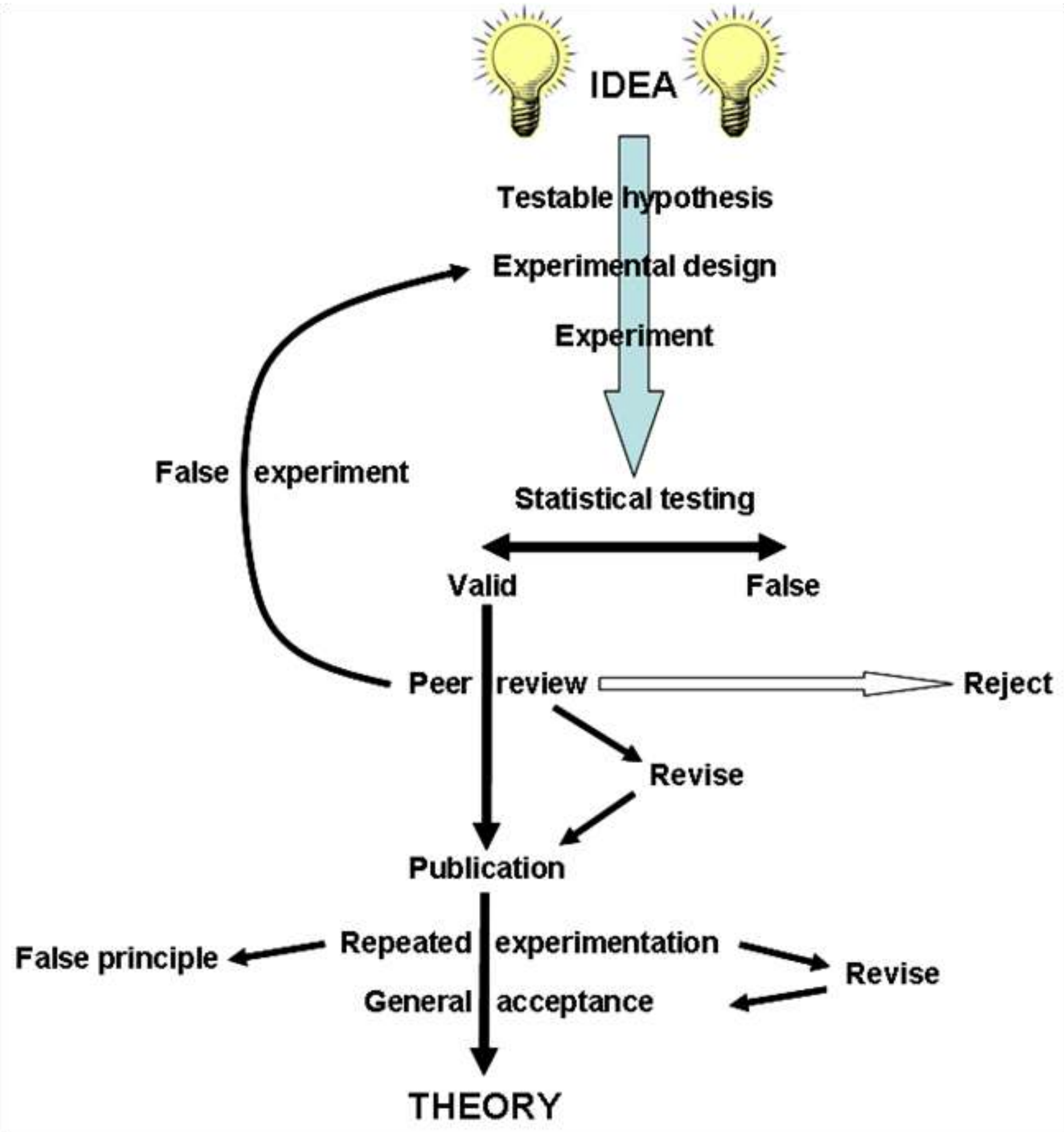


Figure3: The steps involved in taking an idea and getting it accepted as a theory. Adapted and expanded from Cross (2000).

Formulating an experiment and hypotheses

"To call in the statistician after the experiment is done may be no more than asking him to perform a post-mortem examination: he may be able to say what the experiment died of." R.A. Fisher, Indian Statistical Congress, Sankhya, ca. 1938.

Now that we are familiar with the general steps involved in basic experimental design, we can begin to look at some of these steps in closer detail. Let us first focus upon **hypotheses.** What is a hypothesis?

- A hypothesis, is "*a tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation"* (a definition supplied by www.answers.com).

Formulating a hypothesis is the first step in experimental design and it is used to express the aims of your project in terms of one or more simple **testable** hypotheses (H).

Let's look at an example of an untestable and a testable hypothesis. The example is presented in Figure 4 "Tilapia dream of prawns", this hypothesis is untestable until we have a way of recording and visualising the thoughts and dreams of tilapia.

Figure 6: An untestable hypothesis, "Tilapia dream of prawns". (Sources: http://sofia.usgs.gov/sfrsf/rooms/species/invasive/focus/tilapia.jpg and www.dram.org/rd/artwork/prawn.jpg).

The example presented in Figure 7, however, "Fish show improved growth if you feed them", is testable. Here, you can set up an experiment where you take a known number of fish, you weigh them at the start of the experiment and record the weight of the food that you give them each day and then after certain, determined number of days, you weigh the fish again and record their new weight. Of course you must also set up an appropriate control where you have tanks of fish that were not fed over the experimental period. It is important to note, however, that both the test groups (fish that will be fed over the experimental period) and the control groups (fish that will not be fed over the experimental period) are taken from the same pool of fish and that each group of fish are weighed and analysed statistically to ensure that there are no differences in the weight of the fish **before** starting the experiment. Alternatively, you could set up a null hypothesis (H_0) which would be to suggest "Fish do not show improved growth if you feed them".

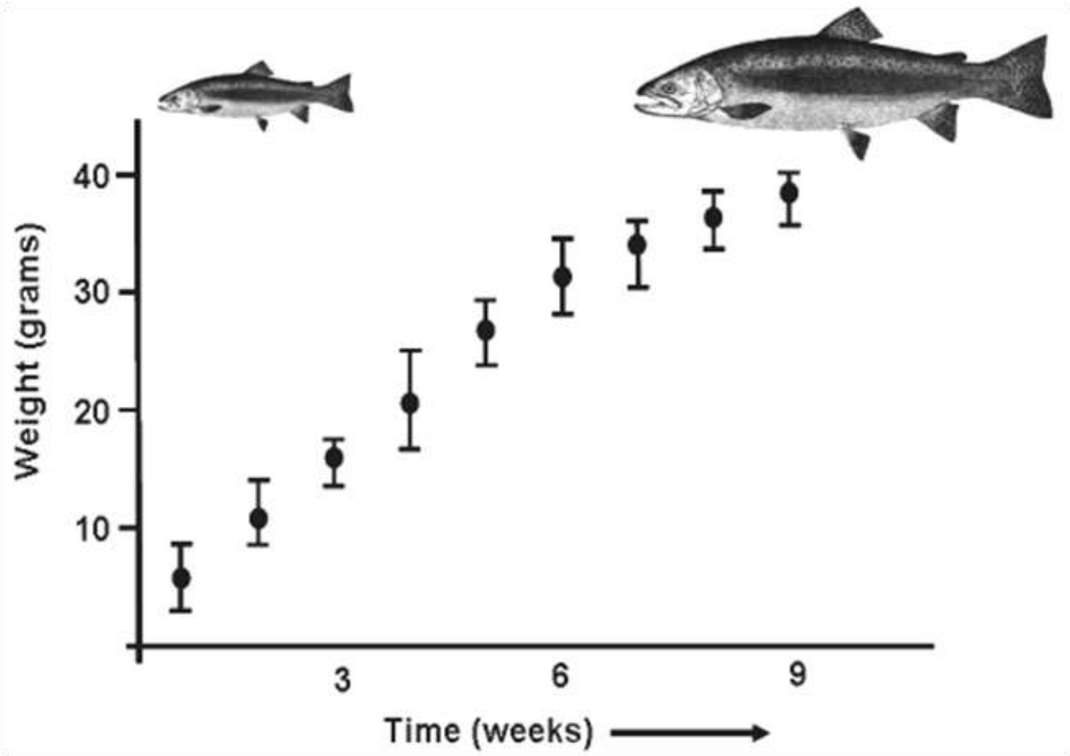


Figure 7: A testable hypothesis "Fish show improved growth if you feed them". The graph above shows the average weight and range of 30 fish measured at each time point. (Image source: Maitland , P.S. (1972) "A key to the freshwater fishes of the British Isles")

Of course to test your hypothesis, you will need to measure your results in some way. The measurements you choose will determine the statistical tests that you can perform following the completion of your experimental work or observations. It is important to remember that statistics are tools that you use and not an objective. You must understand what you are trying to do, if you do not you will not be able to ask the right questions of your work and apply the right techniques. In short, you can think of the process as:

Flow diagram taken from "An introduction to statistics" (www-micro.msb.le.ac.uk).

Types of data

We can say that our data consists of **observations** which are values or **variables**. Let us briefly consider some example of variables (or classes of information):

- Number of live births : coded 0, 1, 2, 3,......
- Geographical region : Europe, Asia, UK, USA, etc.
- Weekly earnings : From $500 upwards
- Size of fish : From weight/length at start
- Number of parasites : 0 upwards per unit area
- Dose of chemical : 0 upwards
- Behaviour : 'Non smoker', Ex smoker'; 'Occasional smoker'; ' Heavy smoker'
- Gender : Male or Female

Etc, etc....

I am sure you can think of many more than this.....

Variables that are experimentally manipulated by the experimenter (e.g. water flow rate, temperature in an aquarium, amount of food given, etc) are called **independent variables**. Variables that are measured by the experimenter during the experiment (e.g. growth rate in a feed trial etc) are called **dependent variables**. Any other factor that may affect the dependent variable are called **confounding**, **extraneous** or **secondary variables** – unless they are the same for each group being tested comparisons will be unreliable.

There are, however, two main types of data that can be collected and these are:

Quantitative data: Measurements of objects or events i.e. how much or how many of something

Qualitative or **Categorical data:** Provides labels or names for categories of like items, i.e. a set of observations where any single observation is a word or code that represents a class or category.

Qualitative or categorical variables

Let us now consider some examples of some categorical variables:

- Gender: Can only be male or female
- Smoking behaviour: Can only be non-smoker, ex-smoker, occasional smoker or heavy smoker
- Eye colour: Could be black, brown, blue, green, hazel, grey etc
- Hair colour: Could be black, brown, blonde, auburn, red, grey, white etc
- Geographic region: Could be anywhere and have different sizes – continent, country, state, county, town, street, or designated described area, etc.

The examples above and indeed all qualitative or categorical variables can be divided into **Nominal** or **Ordinal**.

Ordinal variables are variables with an ordered series which can be ranked. Look at the examples below.

In the first staff at the Institute of Aquaculture either 1) "greatly dislike fish", 2) "are indifferent to fish" or 3) "greatly like fish".

In another example of an ordinal variable, staff members at the Institute of Aquaculture can be categorized as either “non-smokers”, “ex-smokers”, “occasional smokers” or “heavy smokers”.

“Non-smoker” “Occasional smoker” “Heavy smoker”

Ordinal variables can be further sub-divided into **interval variables** and **ratio variables**. An interval variable is a variable that is equally spaced, for example if we consider water temperature, the difference between 24^{o}C water temperature and 25^{o}C, is the same as the difference between 30^{o}C and 31^{o}C water temperature. Interval variables **do not have a true zero**, for example, 66^{o}C is not necessarily double the temperature of 33^{o}C. Ratio variables, however, are variables that are also spaced with equal intervals but they **do have a true zero** point e.g. age.

Nominal variables are variables which do not have an inherent order or ranking sequence, for example “male” or “female”. It is important to note that the categories are simply labels and that one category cannot be ranked “greater than” or “less than” another category, as can ordinals. For example, we cannot say that “blue eyes” are greater than “brown eyes”. The categories that we create are often conveniently designed so that we can class numbers but we do not imply any relationship between the individual categories.

Quantitative variables

Quantitative variables are commonly the measurements of objects or events i.e. “how much” or “how many” of something. Let’s look at some examples of some quantitative variables.

The number of fish eggs hatching per batch

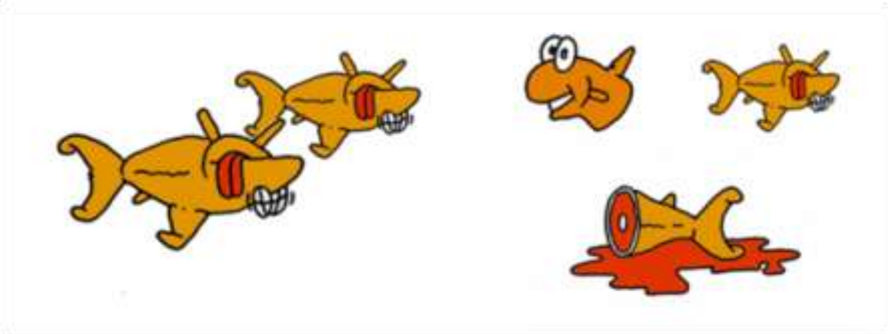
The length of fish

The weight of fish

The cost of rearing each batch of fish etc etc

Here, we attempt to quantify something by counting or measuring. There are also two major sub-groupings of quantitative data – **discrete variables** and **continuous variables**.

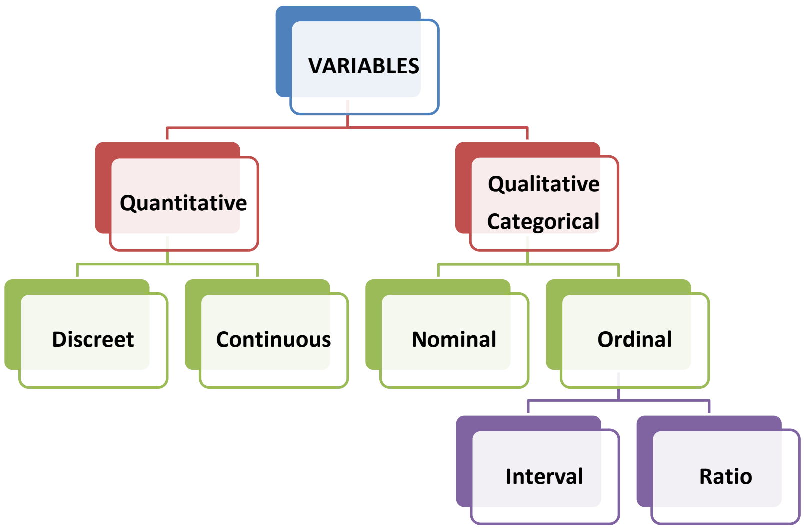
Discrete variables are any kind of count; they take values in a restricted set such as integers {0, 1, 2... }. For example, consider the research question "How many dead fish are there in a tank in response to a particular treatment?" You cannot, for example, have 1.5 dead fish, you can only have 1 dead fish or 2 dead fish etc.



Continuous variables are any kind of measurement, which can take any real number value. For example, height, weight, age, concentration etc....

Summary

In summary, we know that data are numerous types of observations of different variables. These variables can be:



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Many thanks for your attention today

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Lifelong Learning Programme

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