Lecture 1: Introduction to the Design of Experimental and Observational Studies

STA 106: Analysis of Variance

Suggested reading: ALSM Chapter 15

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Introduction to the Design of Scientific Studies

Motivations

Broad Types of Scientific Studies

Basic Terminology

Most Common Designs of Scientific Studies

- Experimental Studies
- Observational Studies

Philosophy of Science

The major task in any science:

- Development of theory ..... Theories are causal explanations.....
- The goal in every science is explanation, and explanation is alway causal

The perspective on science or scientific methodology (emerged in the West around 1600):

- Empirical observation, and whenever possible, experimentation

Why?

The essence of experimentation:

An attempt to discover the effects of presumed causes

It's because of their contribution to the understanding of causal processes
that experiments play a central role in science

Experiment: one of the two greatest achievements on which Western science is based on

The Contribution of Statistics to Science

Statisticians

- Do not perform experiments
- Has no expert knowledge on subject matters
- BUT, researchers always turn to Statisticians for help, both in planning their studies and in drawing conclusions from the results

What can statistics contribute?

- Inductive inference that generalizes from the part (empirical observations = sample or data) to the whole (population model)
- Statistical analysis:

  Reasoning from data to an inferred model
- It's this applied inductive logic of statistics that makes it uniquely positioned to contribute to science's glory

This course is about: ANOVA

ANOVA (Analysis of Variance) models is a collection of specialized linear statistical models

- Originally motived by the need to analyze data arise from experiments or experimental studies
- Modern development can deal with both experimental and observational studies

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Statistical design of scientific studies

Proper design is critical

- Interpretation of results is largely determined by how studies were conducted
- A poorly designed study can't be rescued with most sophisticated statistical analysis

Experimental study

Causal-and-effect relationships

Observational Study

Association between explanatory factors and response variable

Not causation

Experimental Studies

In an experimental study,

randomization is used to assign a set of treatments to the experimental units,
and the observed outcomes among the treatment groups are compared to assess treatment effects.

Causal-effect relationships between the experimental factors and the outcome variable can be established.

Objective of the study:
To study the effect of vitamin C on the prevention of colds

The experiment:
Of the 868 children,
half were randomly selected for the experimental group which received daily vitamin C,
the remaining half made up the control group which received a daily placebo tablet

Outcome:
Average number of colds per child were recorded at the end of the study period

☑ A completely randomized design
☑ A clinical trial

A prospective intervention study, where one is interested in comparing the effects of
different treatment interventions starting at one point in time on the outcome at a later point in time.

Observational Studies

In an observational study,

random samples are obtained from two or more populations, and observed outcomes are compared across populations.

The populations are defined by the levels of one or more explanatory factors, referred to as observational factors.

Causal-effect relationship between the explanatory factors and the outcome variables is difficult to establish in an observational study, usually requires external evidence to rule out possible alternative explanations for the observed relationship.

The objective of the study:

To assess the effectiveness of a teaching method workshop

The study setup:

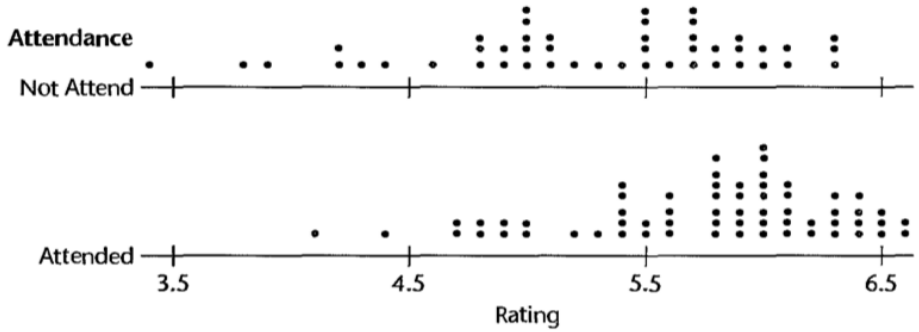
110 faculty were offered the opportunity to participate in a non-mandatory workshop on teaching methods

63 faculty volunteered to attend, while the others did not

The outcome:

At the end of the following academic year, the teaching performances of faculty who attended the workshop versus those who did not attend were compared

Observational Studies



The seminar was effective in improving the quality of teaching?

Better or more highly motivated teachers volunteered for the workshop

Participate in the workshop

Quality of teaching

Ideally, if possible, how to evaluate the effectiveness?

Randomization would tend to balance out the differences in other factors, such pre-workshop teaching ability or motivation, leaving the observed differences attributable to the experimental treatment or experimental factor.

Mixed Experimental and Observational Studies

The objective of the study:

To assess the effectiveness of the two training programs

The study setup:

A company has three regional training centers in the U.S.

Trainees from the region were randomly assigned to one the two training programs.

Training centers were not randomly assigned to subjects, instead, each trainee was assigned to the regional center because of home location

☑ Two-factor study

Training program: experimental factor

Training center: observational factor

☑ Randomized Block Design

Blocks are the training centers

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Basic Terminologies

Factors

A factor is an explanatory variable to be studied

An **experimental factor** is one where the level of the factor is assigned at random to the units.

An **observational factor** is the characteristic of the units, which is not under the control of the investigator.

A **factor level** is a particular form of the factor, or a particular value the factor can take.

Studies differ by the number of factors included

Single-factor studies: only one factor is included

Multi-factor studies: two or more factors are included

Crossed: when all combinations of the levels of two factors are included in the study

Nested: when levels of one factor are unique to a particular level of another factor

(a) Crossed Factors—Chemical Yield Experiment

Solvent Conc.	Temperature		
	Low	Medium	High
Low	X	X	X
High	X	X	X

(b) Nested Factors—Production Yield Experiment

Plant	Operator								
	1	2	3	4	5	6	7	8	9
1	X	X	X						
2				X	X	X			
3							X	X	X

Basic Terminologies

Treatments

The set of treatments is determined by the combination of the factors and their levels

In single-factor studies,

each factor level constitute a treatment

In multi-factor studies,

a combination of factor levels constitute a treatment

Control treatment:

apply the identical study procedures except that none of the treatments are applied

Serve as the proper standard of comparison

Basic Terminologies

(Experimental) Units

Objects or entities to which the treatments are applied in an experimental or observational study

Basic Terminologies

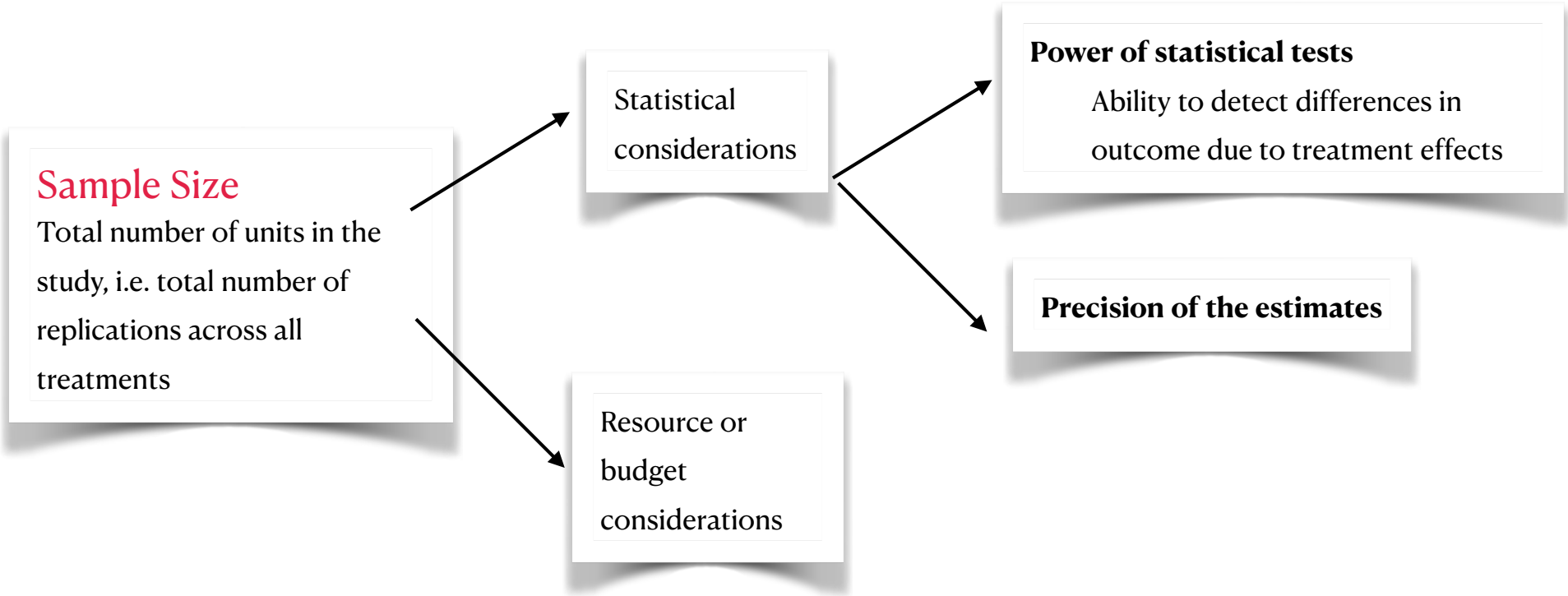
Replication or Replicates

Multiple units within the same treatment

Why multiple replicates in one treatment?

> When a treatment is repeated, any difference in the response for the same treatment is due to other extraneous factors not of primary interest.
>
> Replication makes it possible to estimate this source of variance (that is not due to factors under study, but are influenced by other extraneous factors) which will be crucial for any inference work

Basic Terminologies

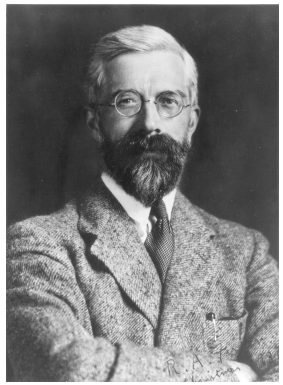


Basic Terminologies

Randomization

(British Statistician Sir Ronald Fisher 1920s)

What might go wrong if assign treatments to units on systematic or subjective basis?



Better or more highly motivated teachers volunteered for the workshop

Participate in the workshop

Quality of teaching

Sanitary condition of different schools

Flu virus outbreaks in one school

Vitamin C

Getting colds

Assignment of treatments on subjective basis:

self-selection

The bias due to self-selection is **selection bias**

Basic Terminologies

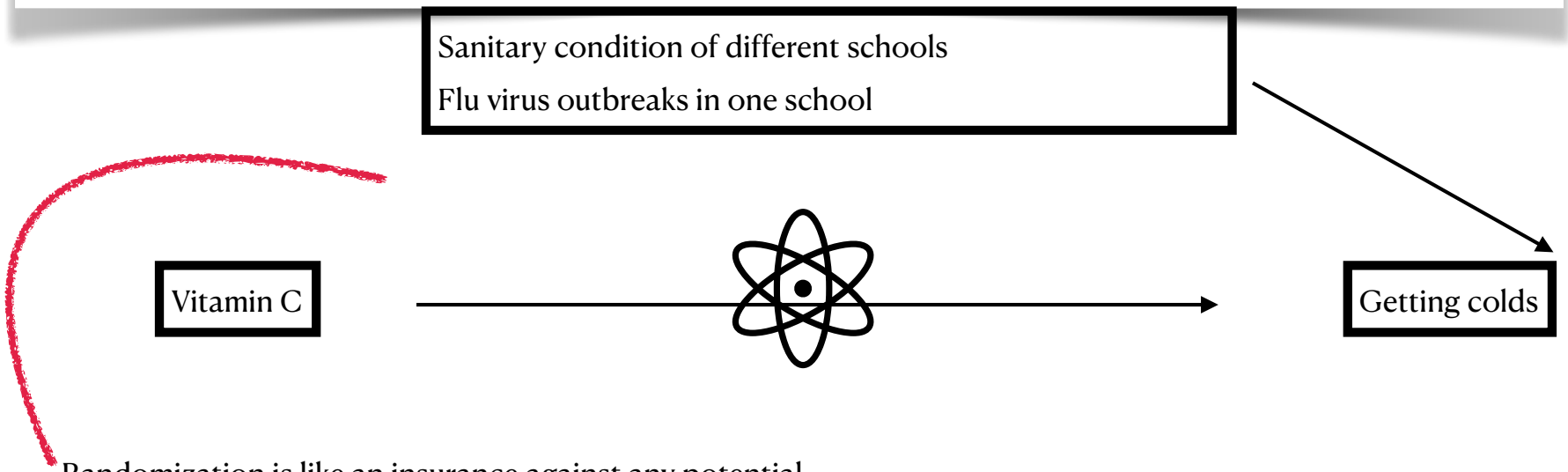
With randomization, the treatments are assigned to units at random.

Randomization tends to

- average out whatever systematic effects between the different treatment groups, apparent or hidden
- such that the comparisons between the response in different treatment groups only reflect the differences due to treatment, i.e. treatment effect.

In other words, randomization effectively

- cut off the influence of extraneous factors not under the direct control of the investigator
- exclude the possibility of selection bias



Randomization is like an insurance against any potential trouble that would cause bias, may or may not be realized

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Design of Experimental Studies

Completely Randomized Design (CRD) or Completely Randomized Experiment

In a completely randomized experiment, a fixed number of subjects is randomly assigned to receive each treatment.

The simplest completely randomized experiment takes an even number of units and divides them at random in two groups, with exactly one-half of the sample receiving the active treatment and the remaining units receiving the control treatment.

E.g. vitamin C clinical trial

Possible drawbacks of CRD

a study with N=20 units, ten men and ten women, where the outcomes are a priori thought to vary substantially by sex.

Then, although a completely randomized design would ensure that ten units get treated, there is the possibility that all ten of them are men (or women).

In that case, the difference in outcomes for active and control treatments could be due to sex differences rather than treatment effects.

Design of Experimental Studies

Randomized Block Design or Stratified Randomized Experiments

Units in the study is first partitioned into blocks or strata defined by covariate(s)
so that the units within each block are similar with respect to those covariate(s) that are thought to be predictive of outcomes.

Then, within each block, we conduct a completely randomized experiment.

Treatment effect is obtained by combining the estimated effects from all blocks

E.g. two training programs in three regional training centers

When subjects as blocks, randomized block design is called "Repeated Measures Design"

Randomized Complete Block Design

When each treatment is replicated exactly once in each block

Design of Experimental Studies

Blocking

What are the benefits of randomized black design versus completely randomized design?

- **Control balance in the the covariates** used to define blocks, so to reduce the bias in the evaluation of treatment effects

  e.g. Randomization alone can't guarantee the same number of males and females in two treatments

- **Lead to more precise inferences**

  Blocking is a technique can be used to increase precision in a randomized experiment

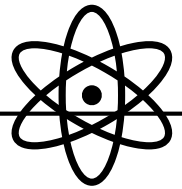
  Precision of estimates depends on the variation due to extraneous factors

  Control (by blocking) factors that affect the outcome will remove such variation partially, the part that is due to the blocking variable(s)

Design of Experimental Studies

Gender, Age, general health status of the child
Sanitary condition of different schools
Flu virus outbreaks in one school
.....

Vitamin C → Getting colds



Restricted Randomizations							
Male	1	2	3	4	...	433	434
Treatment:	Vitamin C	Vitamin C	Placebo	Vitamin C	...	Vitamin C	Placebo
Female:	1	2	3	4	...	433	434
Treatment:	Placebo	Vitamin C	Placebo	Vitamin C	...	Placebo	Vitamin C

Within blocks, units are alike respect to the gender → we would be able to remove partial variation due to gender

↓

Error variance decrease → Precision of any estimate increase & reduce potential bias due to unequal gender in two treatments

Design of Observational Studies

Cross-Sectional Studies

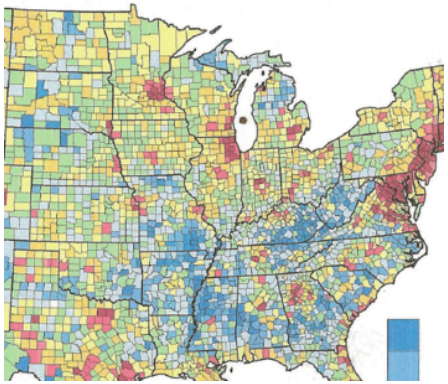
Measurements (both observational factors and the outcome) are taken simultaneously, at a single point in time or a single time period.

Exposure to a potential causal factor and the outcome are determined simultaneously

Provide a “snapshot” of the factors and the outcome

A marketing department is interested in to compare the household incomes by geographic location in a major city
Random samples of households were selected within each geographic zip-code area

Can you say more than “which geographic area is associated with higher/lower household income”?



Design of Observational Studies

Prospective Studies or Cohort Studies

Groups are formed in a nonrandom manner according to the levels of a hypothesized potential causal factor

These groups are then observed over time and an outcome variable of interest is recorded

Particular suited to answer "What is going to happen?"

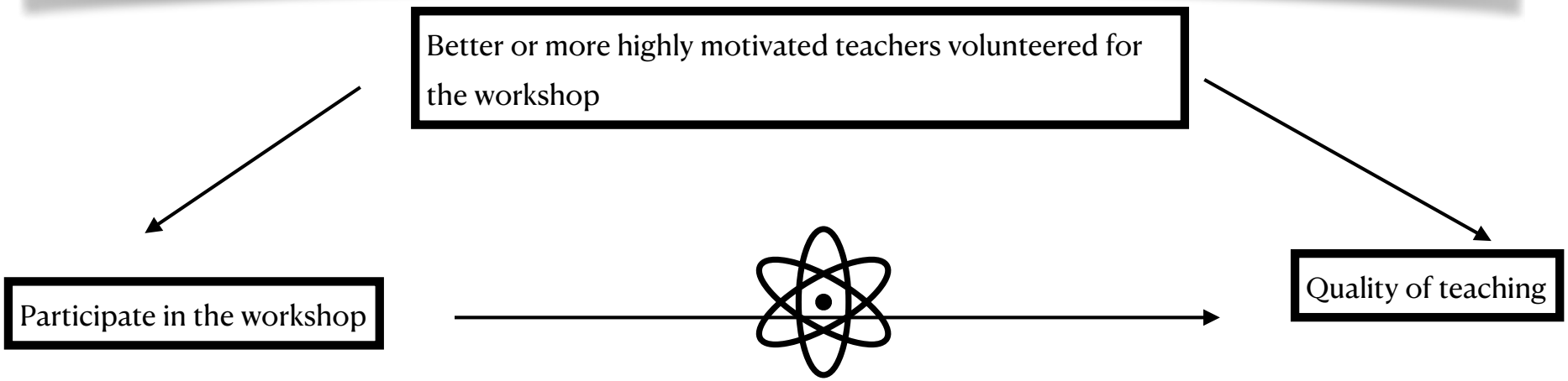
This obeys the rule that "cause precedes effect"

Medical studies:

Explore potential links between estrogen therapy and heart disease

From medical histories, identity women who received estrogen supplements for a sustained period, and women who did not

Follow up with them for several years, compare the rates of heart disease



Design of Observational Studies

Retrospective Studies or Case-Control Studies

Groups are defined on the basis of an observed outcome

Differences among the groups at an earlier point in time are identified as potential causal factors

Particular suited to answer “What has happened?”

This obeys the rule that “cause precedes effect”

Medical studies: (to study rare event diseases)

Explore potential links between life styles and lung cancer

Two groups of subjects were formed: one was lung cancer patients, one was healthy individuals

Look back in time to collect different measurements concerning the lifestyles of those individuals, and compare which specific lifestyles differ between the two groups

These studies led to hypotheses about the causal effects of cigarette smoking

Design of Observational Studies

Why observational studies at all then?

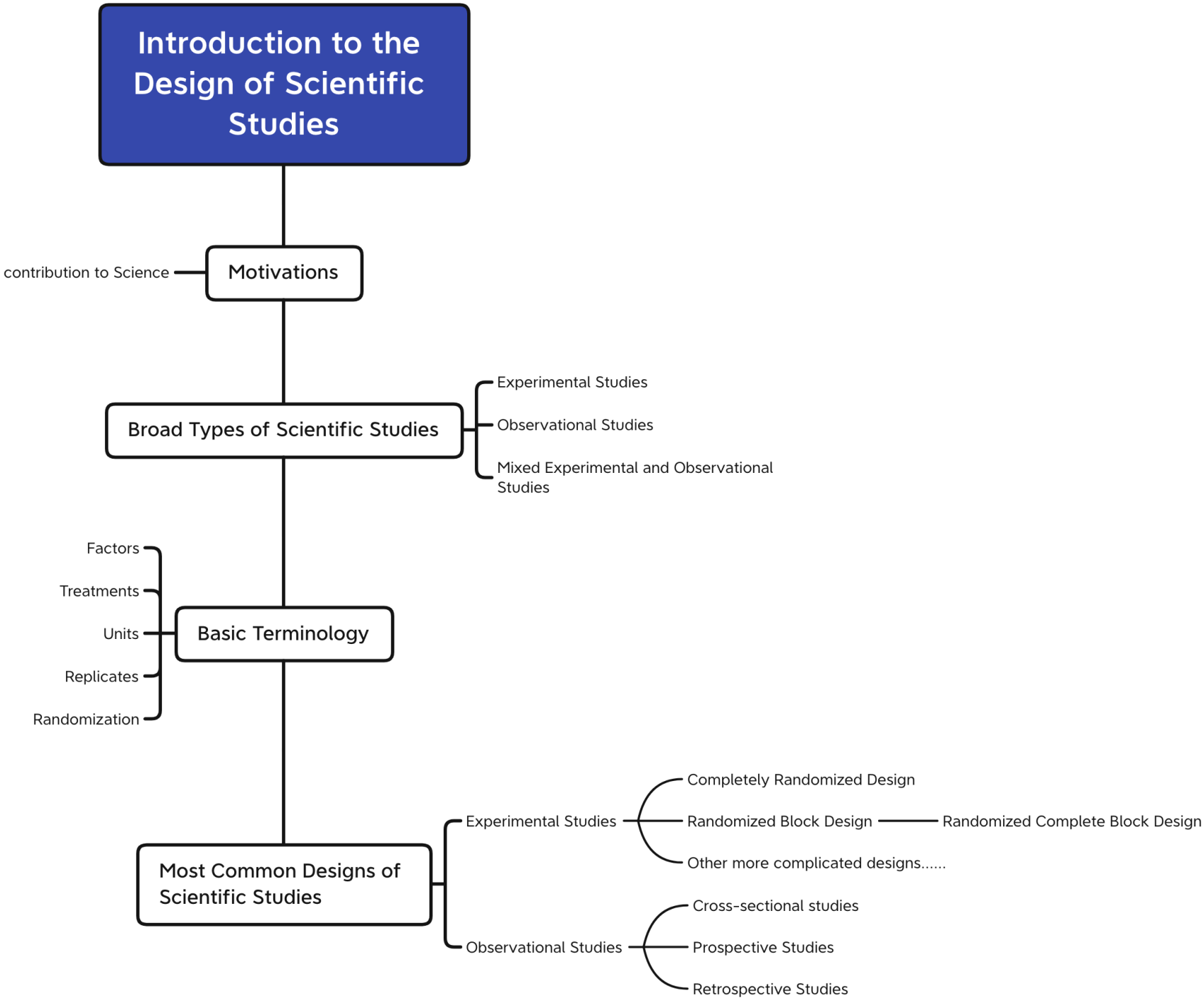
It is sometimes impossible to do randomization, due to ethical reasons, practical feasibility, etc.

Be cautious on your conclusions/interpretations:

Sometimes the data and even the statistical analysis could be very similar for an experimental study and for an observational study.

However, the interpretations of the results are different. You usually can only make a statement on association for an observational study and should be very cautious on drawing any conclusions about cause-and-effect relationship.

Summary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Other more complicated designs.....
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