MSc Applied Information and Data Science

HSLU Lucerne University of Applied Sciences and Arts

Data Analytics for Data Scientists

Design of Experiments (DoE)

Lecture 02: Principles

2025

Prof. Dr. Jürg Schwarz

Program: 16:15 until 17:55

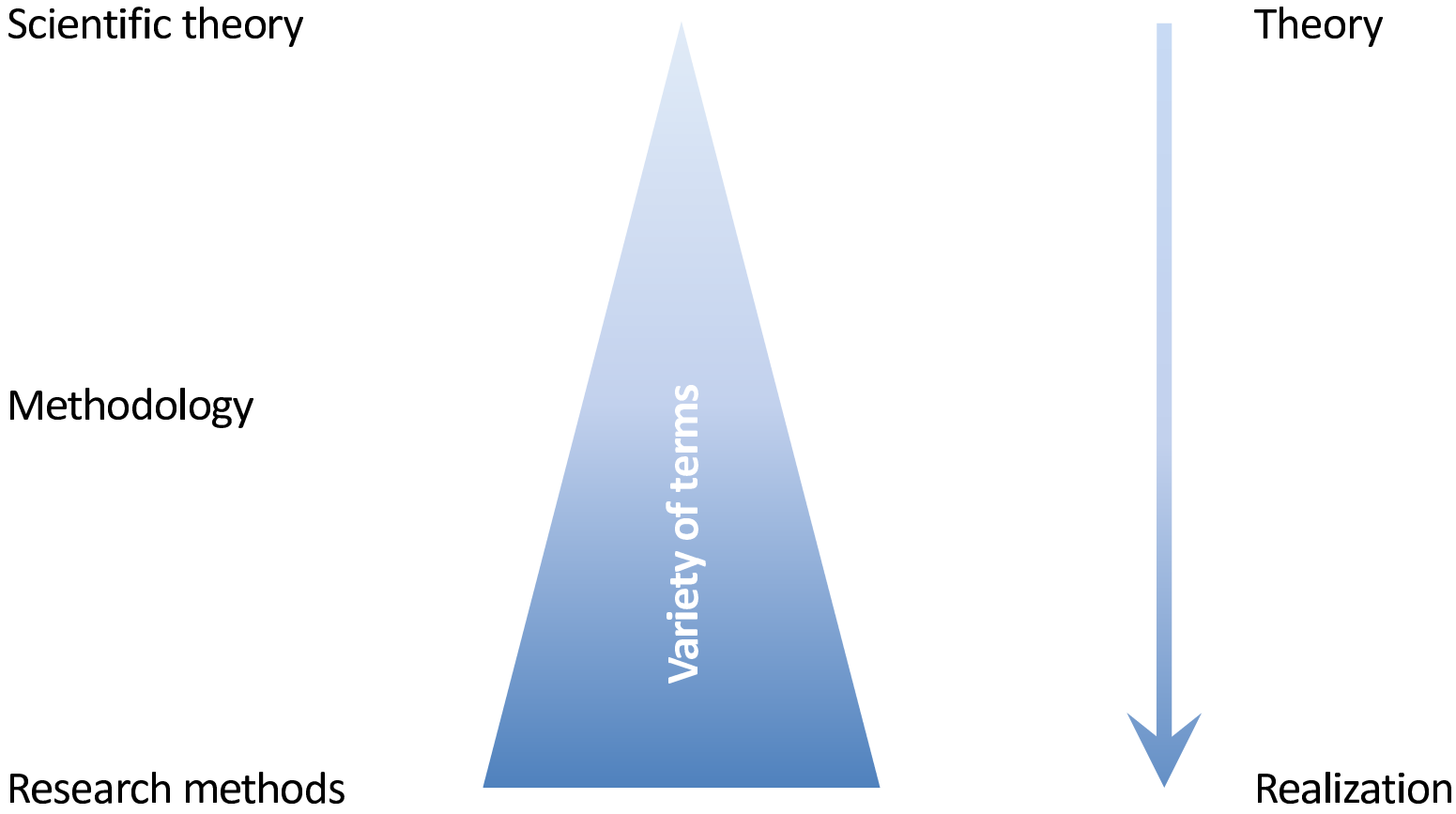
16:15	**Begin of the lesson**
	Lecture: Jürg Schwarz ◦ A brief introduction to scientific theory ◦ Research process ◦ Definition & properties of study design ◦ Preview of Lecture 03
	Tutorial: Students / Jürg Schwarz / Assistants ◦ Working on the exercise ◦◦ Support by Jürg Schwarz / Assistants
17:55	**End of the lesson**

Detailed table of contents → Slide 24

Research Methods: A brief introduction to scientific theory

Scientific theory / Methodology / Research methods

Hierarchy and terms / From theory to realization



Scientific theory …

- examines whether and how scientific knowledge can be obtained.
- is a branch of philosophy that deals with the epistemology of scientific knowledge and scientific methods, and with research.
- analyzes the practices that generate scientific knowledge and examines their institutional and social context in which these take place.

Methodology …

- focuses on the underlying considerations, decisions and justifications of the approach used in scientific research projects.
- provides the instructional framework on how to proceed in order to gain scientific knowledge.
- does not comprise a strictly formal set of rules but offers a diverse and pragmatic set of choices that are linked to human action.

Research methods …

- are systematized procedures and approaches for obtaining knowledge.

Selection of positions held in scientific theory

Classical rationalism

- Reason precedes experience and there are so-called "innate" concepts of reason.

  René Descartes (* 1596 La Haye en Touraine; † 1650 Stockholm)

Inductive empiricism

Empirical research

- Findings are derived inductively based on observations and experiences.

  John Stuart Mill (* 1806 Pentonville, United Kingdom; † 1873 Avignon, France)

Logical positivism

- The use of logic makes it possible to separate science from metaphysics.
  https://en.wikipedia.org/wiki/Logical_positivism

Critical rationalism

Empirical research

- Findings are derived deductively based on observations.

  Karl Popper (* 1902 Vienna; † 1994 London)

(Social) constructivism

- Individuals construct their reality by relating their thinking and actions.
  en.wikipedia.org/wiki/Social_constructivism

Holzer et al. (2012)
According to Wikipedia

What is empirical research?

Approach

Knowledge can be gained only through observation, experiment and experience.

Latin *empīria* = experience

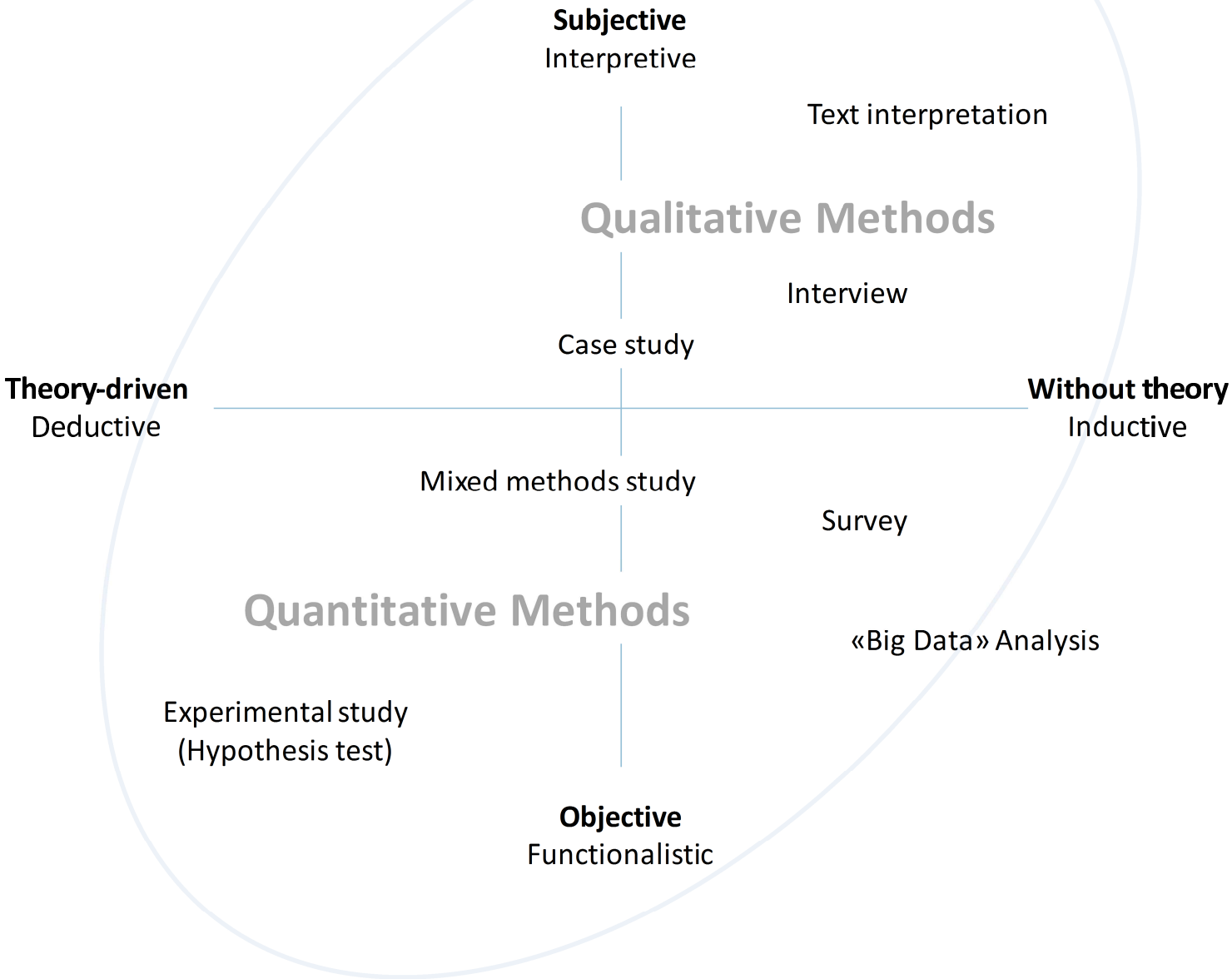
Empirical research looks at the environment by means of **observation** and **experiment**.

There are many research methods for conducting observations and experiments

- Interview
  Example business administration: Interviews with CEOs of banks
- Case study
  Example building technology: Analysis of the energy consumption of buildings
- Survey study
  Example marketing: Analysis of customer satisfaction
- Experiment
  Example music: The role of drums in the perception of groove (here: rocking in rhythm)

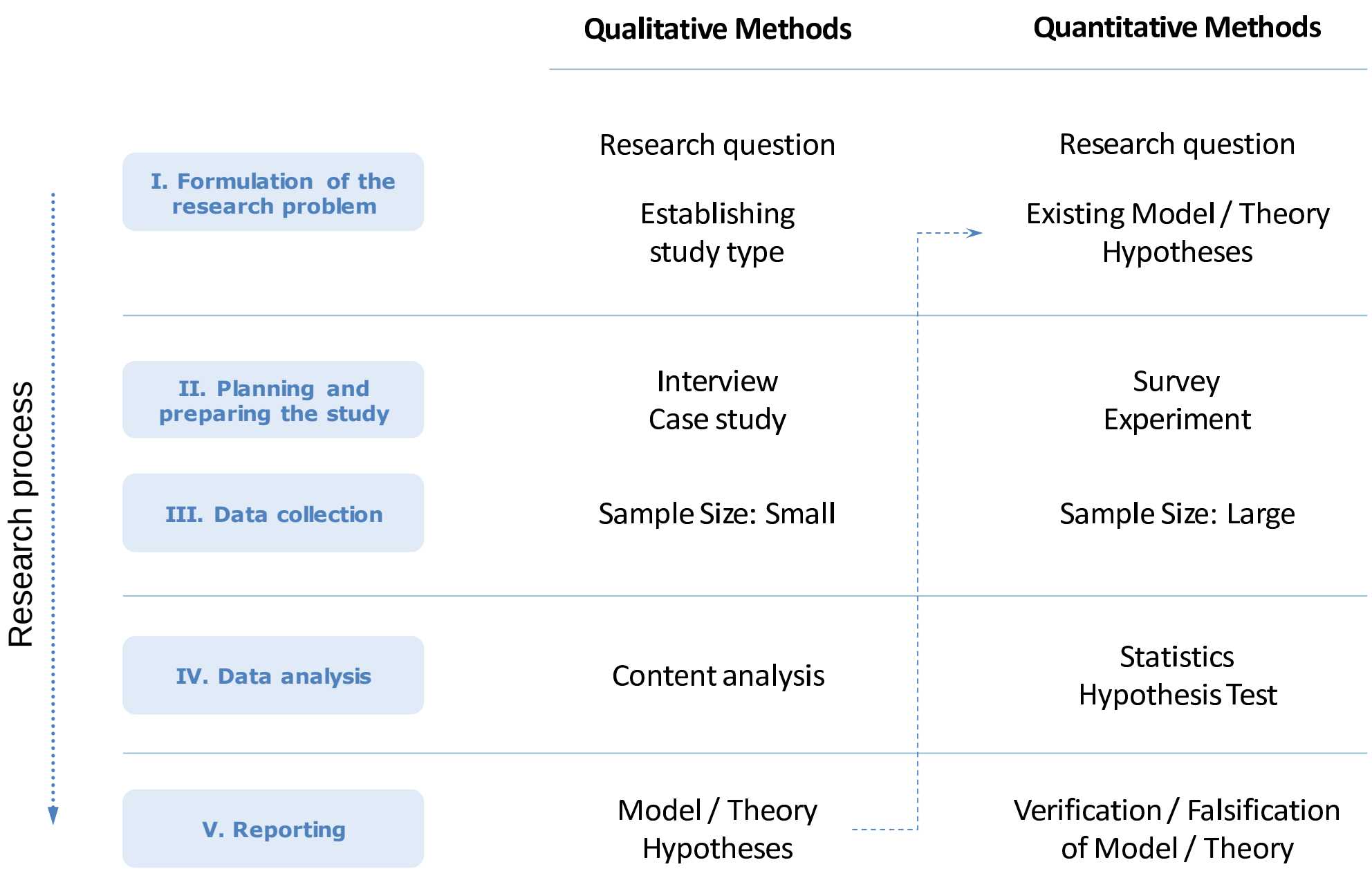
How can the methods be classified?

Landscape of empirical research



Deductive vs. inductive → Appendix Slide 24

Two important areas of empirical methods

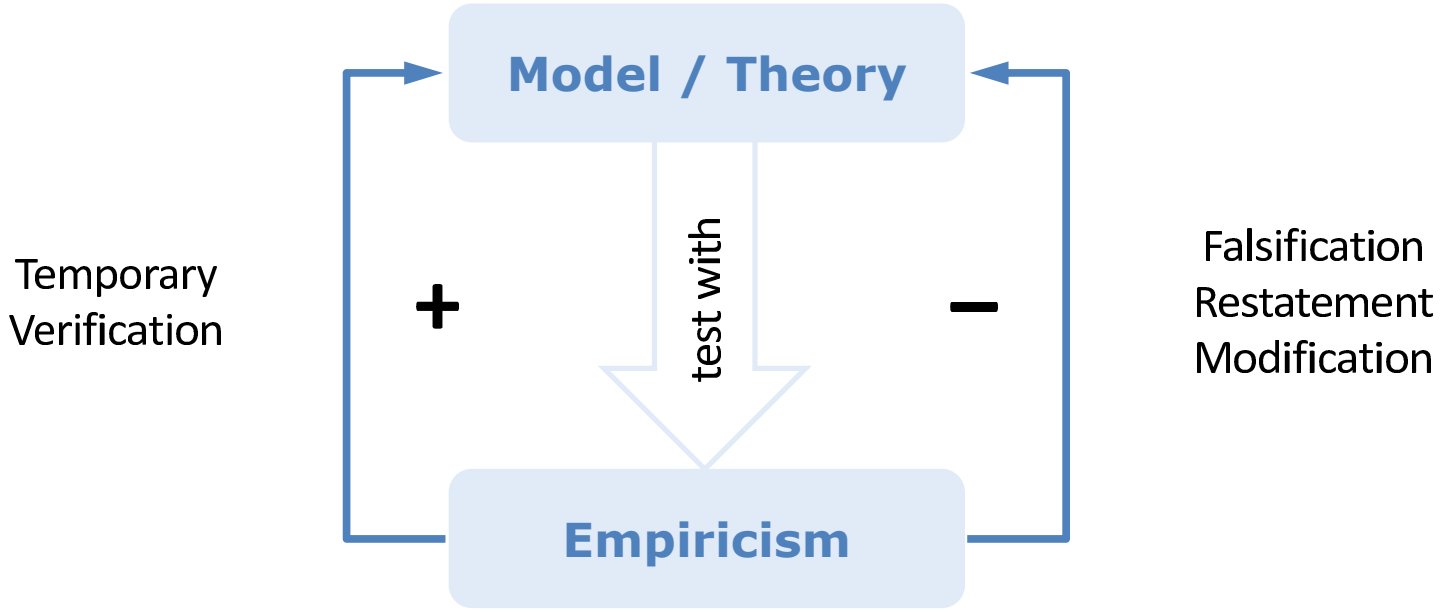


Quantitative methods: Hypothesis test

Research that uses quantitative methods is designed around the principles of **critical rationalism** (Karl Popper, 1902 - 1994)

The approach assumes that a theory can never be finally verified, it can only be falsified.

The process can be shown in a simplified form:



Basic information: Descriptive vs. inferential statistics

Descriptive statistics ...

- describes the data to be analyzed.
- is limited to a sample as a subset of the population.
- does not allow for conclusions to be drawn about the population.

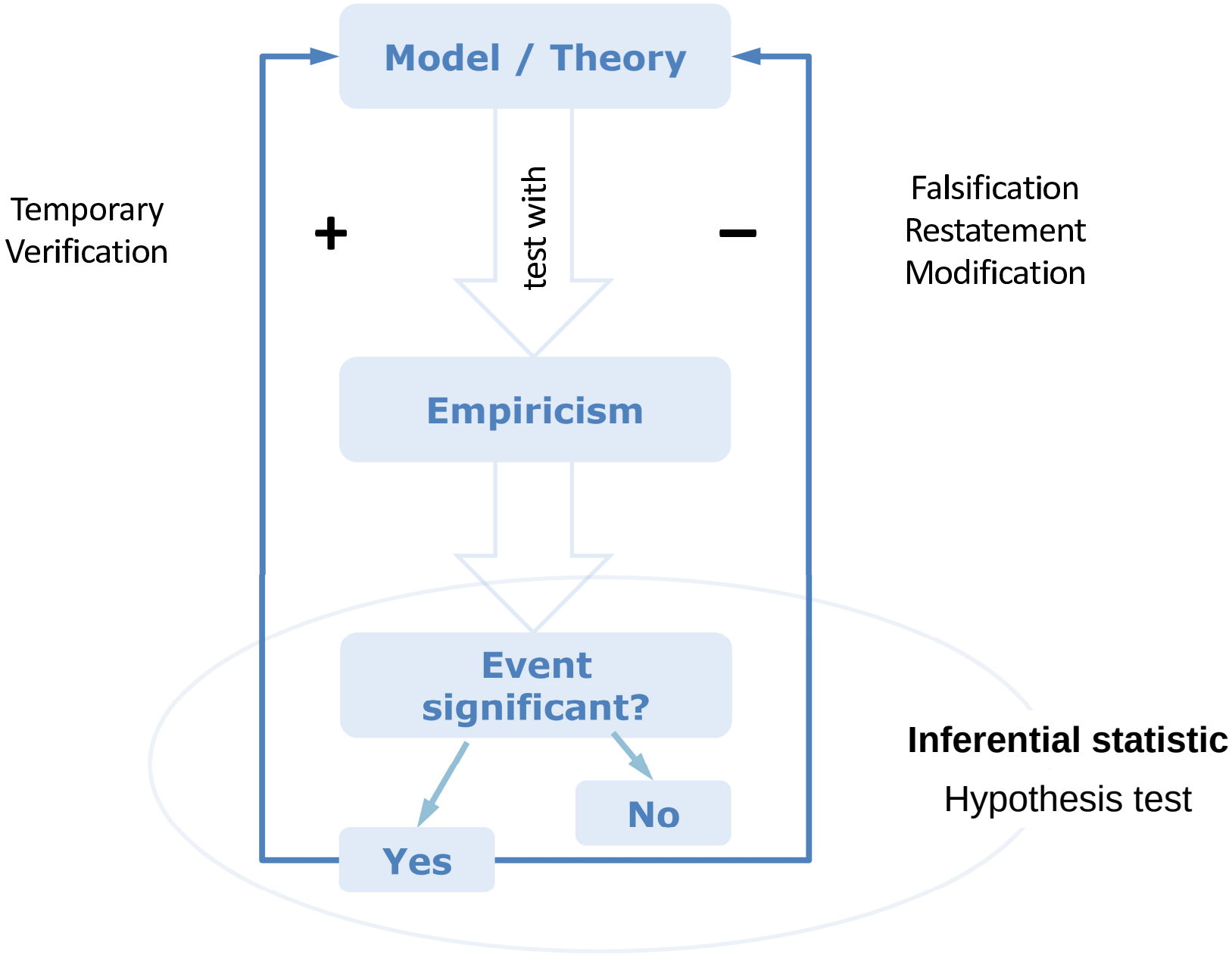
Inferential statistics is a set of methods ...

- for drawing conclusions about the population based on information obtained from a sample.
- that use **statistical hypothesis tests**, especially, as the main component.

Inferential statistics is also known as ...

- **inductive** statistics because the process of drawing conclusions about the population is referred to as **induction**.

Hypothesis tests in critical rationalism



Basic information: Gaining knowledge through statistical hypothesis testing

The logic of statistical significance tests

The classical statistical significance test, also known as "**null hypothesis significance test**" (NHST), was developed as a model mixture of the approaches of Fisher (1925, 1956) and of Neyman and Pearson (1928, 1933)

→ Besides the null hypothesis, it also considers an alternative hypothesis

Null hypothesis and alternative hypothesis

Alternative hypothesis (H_A) is the research hypothesis to be tested that postulates the presence of a certain effect (e.g. a difference) in the population.

Null hypothesis (H_0) postulates the opposite, namely the absence of an effect.

"Is the event significant?" ↔ Hypothesis tests are significant

Yes → Depending on the formulation, the null or the alternative hypothesis is postulated.
Depending on the formulation, the tested model / theory is verified or falsified.

No → The tested model / theory can neither be verified nor falsified.

Research process

Phases in the research process of quantitative empirical methods

I. Formulation of the research problem

1 Research question / Hypothesis formation

II. Planning and preparation of the study

2 Determination of study design

3 Construction of (survey) instrument

4 Definition of sampling procedures

Key Areas Module DoE

5 Pretesting

III. Field phase / Data collection

6 Application of (survey) instrument

IV. Data Analysis

7 Data preparation

8 Data Analysis / Modeling

Module DoE

V. Reporting / Implementation

9 Research report / Presentation

10 Implementation of research results

Adapted from Diekmann (2018) / www.empirical-methods.hslu.ch

Study design → Methodological design of a study

Measuring instrument → Result of operationalization

Operationalization

A process that uses a given set of circumstances to define and specify subsequent research steps with a view to better understanding these circumstances.

See an example on → Slide 26

Sampling procedure

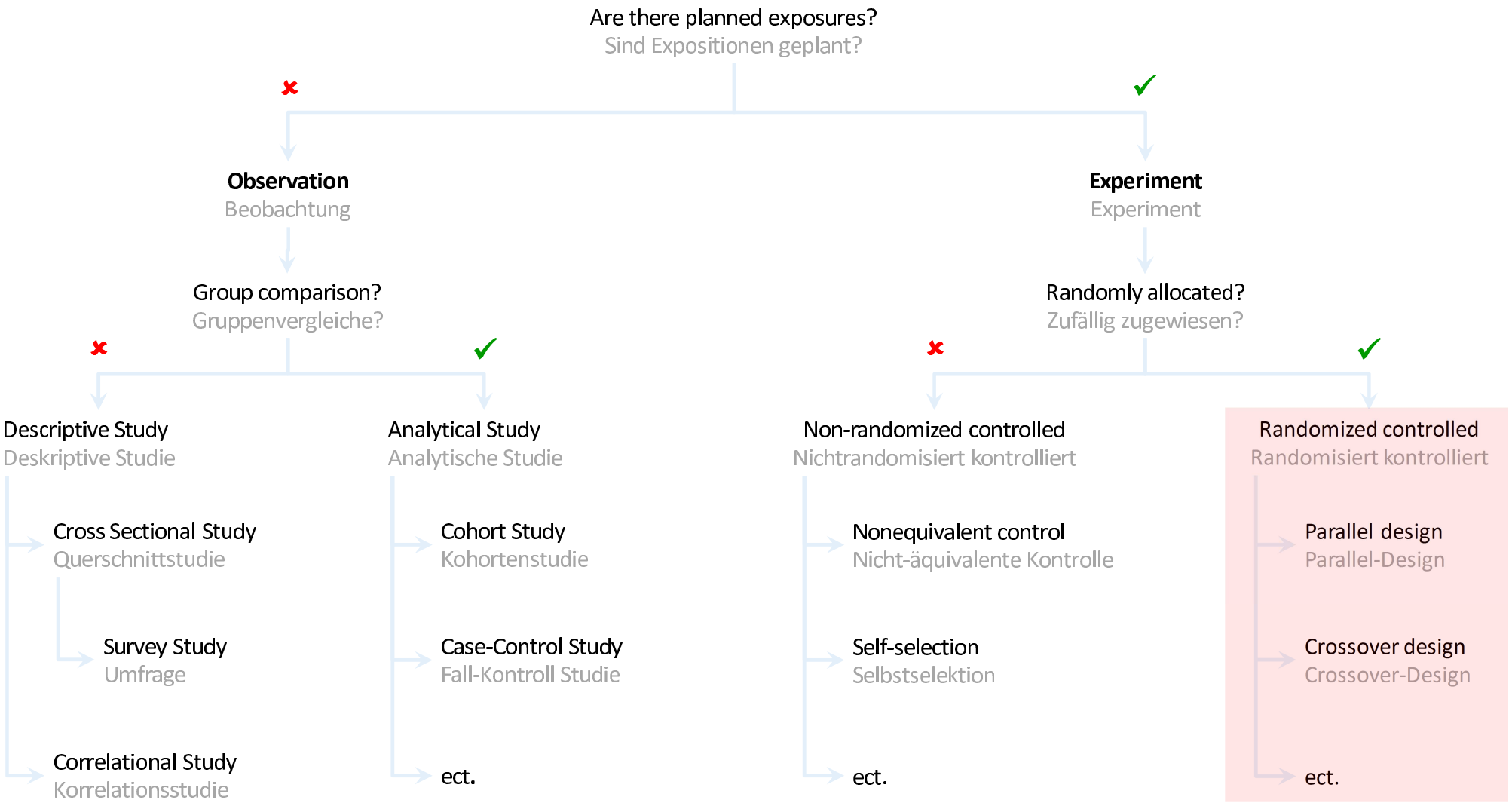
A selection of cases derived from the population and compiled for research purposes that result in statements as part of an empirical study.

Sampling often involves people, but objects of all kinds (e.g. websites, newspaper articles, companies, countries) can also form a population, depending on the research question.

Sample surveys are typical of empirical social research; only rarely are censuses used that examine all cases associated with the population.

Definition of a research study design

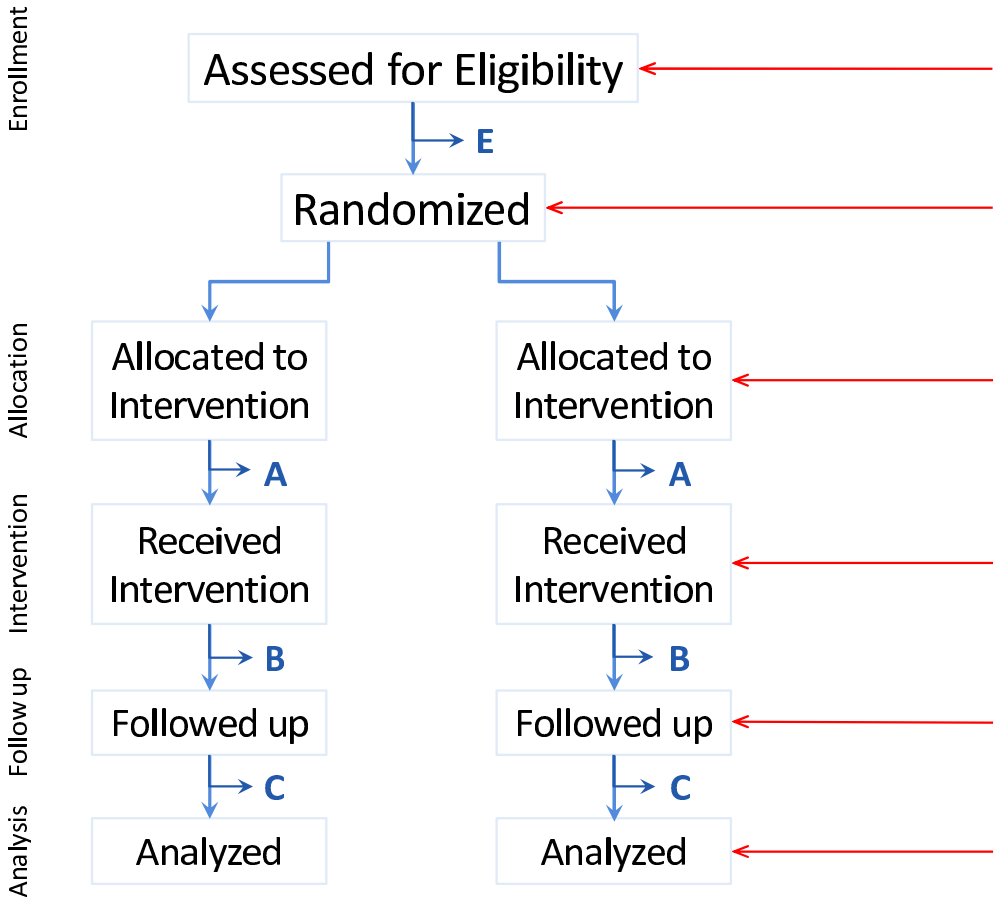
Decision tree for research study design – Part 1



Decision tree for research study design – Part 2

Type: Randomized controlled

Flowchart of the phases of a parallel randomized trial of two groups



Participants are evaluated to determine their eligibility based on whether they meet the inclusion and exclusion criteria.

Eligible participants are randomly assigned to different interventions – in this example there are two interventions*.

Participants are sorted into their randomly assigned groups, determining which intervention they receive.

Participants in both groups will have their specific intervention under study.

Participants in both groups, are monitored over time to record outcomes and any potential nuisance.

Data from both groups are statistically analyzed to assess the effect of the intervention.

E = Excluded
A = No Intervention
B = Lost to follow up
C = Not analyzed

* = A classic setting is that one group is the **control group**, i.e. does not receive an intervention in the strict sense, and the other group **receives an intervention**.

Adapted after CONSORT-Statement

Properties of research study designs

The choice of a suitable research design determines the scientific quality of a study.
The planning of the analysis depends on the research design.

Study type: Observational

Descriptive study

Characteristics

- Descriptive character
- Suitable for **forming** hypotheses (insufficiently accurate for testing a hypothesis)

- Cross Sectional Study → Survey is typical

  Sample with variables of interest are collected and described at a specific time.

  Results of the research project "Quality of Life of Master Students"

- Correlational Study

  Sample of variables of interest are collected and described at a point in time and then correlated.

  Relationship between the time that Master students spend studying on their own and their general quality of life.

  Result: Time spent on self-study and general quality of life correlate.

Study type: Observational

Analytical study

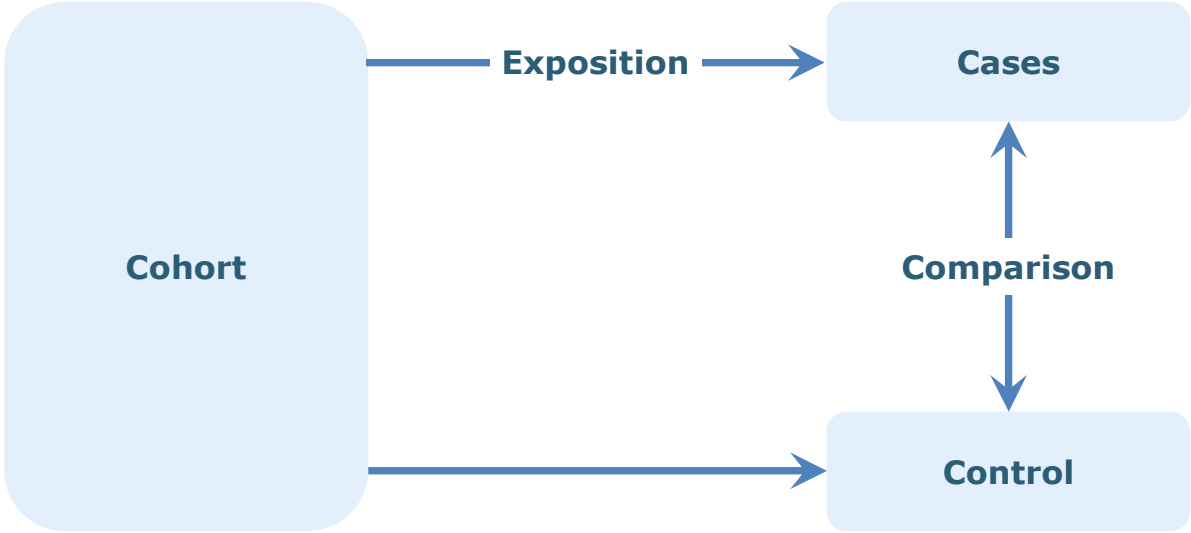
Characteristics

- Identification and quantification of effects / verification of relationships
- Not fully suitable for hypothesis **testing**

- Cohort study (cohort = group of people with comparable initial conditions)

  Two (or more) groups of the same cohort are observed over a defined period. One group is exposed to an influencing factor; the other is not. After the exposure, the two groups are compared.

  Effect of smoking on Alzheimer's disease. Participants were classified as never smokers, […], and current smokers. Compared with never smokers, smokers had an increased risk of Alzheimer's disease. (Ott et al. 1998)



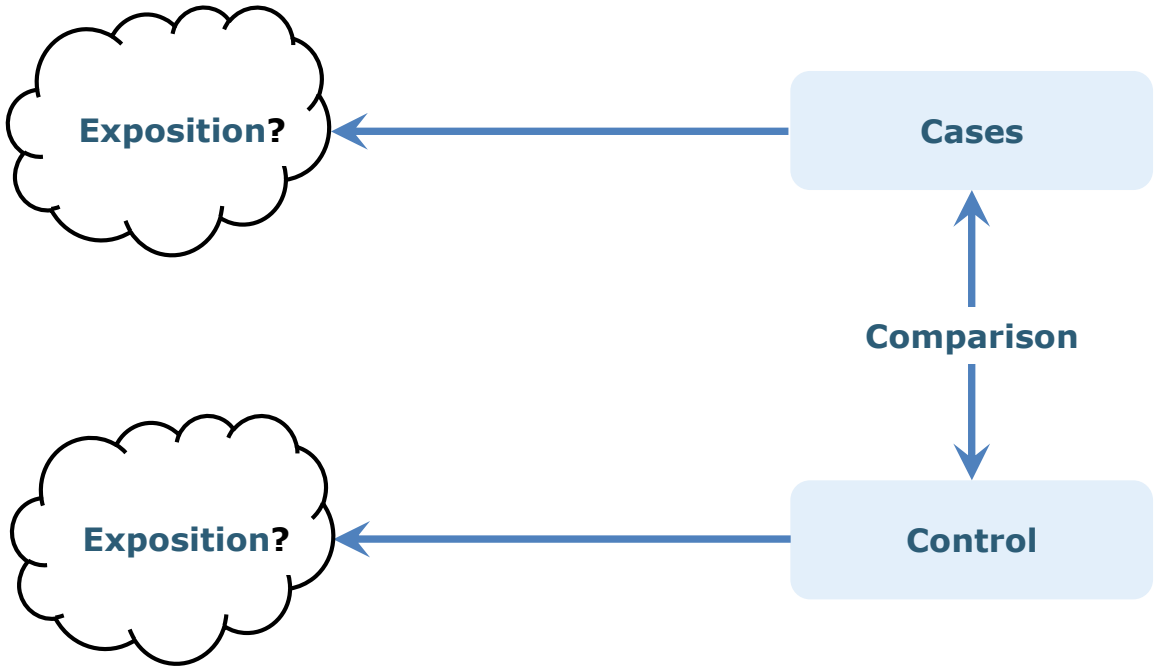
- Case Control Study

This type of study examines how cases and controls differ from having been exposed previously.

Socialization thesis: Pedosexuality is a behavior that is learned during early socialization phases through sexual experiences and relationships between children and adolescents.

This socialization thesis was tested with data from retrospective self-reports and the personal files of imprisoned male pedosexual offenders (cases) and imprisoned male non-pedosexual violent offenders (control). The tests could not confirm the socialization thesis.

However, they identified pedosexual learning effects from victim-perpetrator transitions. (Urban & Fiebig 2010)



Study type: Experimental

Randomized controlled

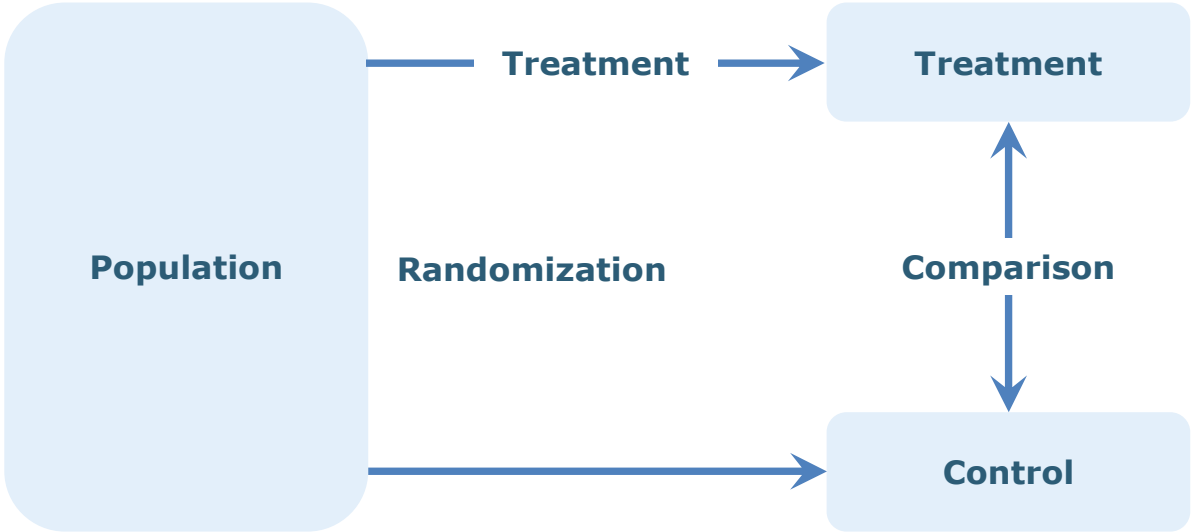
Characteristics

- Suitable for hypothesis **testing**

- Randomized controlled (Randomized Controlled Trial → **RCT**)

  Treatment and control are determined by a random process (randomization) before the intervention.

  Persons in the control and intervention groups received healthcare services as usual provided by community health nurses (23%) and physicians (97%) ... Persons randomized to the intervention group took part in a complementary 9-month in-home HCP (Health Care Provider) delivered by one of four registered nurses with a master's degree in Nursing Science. (Imhof et al. 2012)

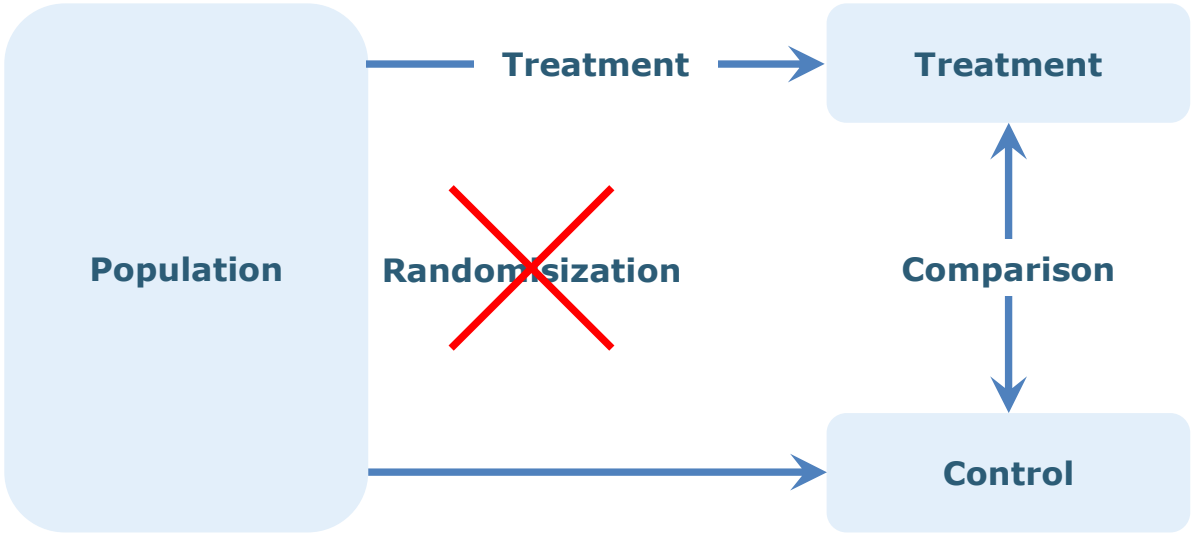


Non-randomized controlled

- Non-randomized controlled (also called a quasi-experimental study)

College students, particularly female students, often suffer from severe stress and poor sleep. Aromatherapy yoga has become a popular exercise in recent years and may help reduce stress and improve sleep quality. We investigated the effectiveness of aromatherapy yoga intervention in reducing stress and improving sleep quality among Chinese female college students. "This study had some limitations. … due to non-randomized allocation into the aromatherapy yoga group since the participants were assigned according to their preference."

The results of the present study showed that aromatherapy yoga could effectively reduce sleep disturbance in female college students. In aromatherapy yoga and yoga-only groups, there were no differences in stress levels or sleep quality between before and after therapy (except on one PSQI subscale of sleep disturbance in the aromatherapy yoga group). (Gao et al. 2022) *Pittsburgh Sleep Quality Index*



Study types that cannot be assigned to any of the above study designs

Typical forms

- Studies with stepped wedge design

  Cluster-randomized study design in which different groups (clusters) switch from a control condition to the intervention at different times.

  In this scheme, the intervention is first introduced in cluster 1 at T2, then in cluster 2 at T3, and finally in clusters 3 at T4.
  All clusters act as control groups at T1.

Time	Cluster 1	Cluster 2	Cluster 3
T1	Control	Control	Control
T2	Intervention	Control	Control
T3	Intervention	Intervention	Control
T4	Intervention	Intervention	Intervention

- Studies with a before / after comparison

  Definition of study type depends on whether the condition before and after an observed exposure or before and after treatment is compared.

- Longitudinal studies

  Developments and changes over time can be determined in two ways:
  - Trend study: Conducted at different times with different samples.
  - Panel study: Conducted at different times with the same sample.

Qualitative studies

- Many study designs and combinations

Preview of Lecture 03

What has happened so far

Scientific theory and the research process

They are the foundation and "road map" for scientific work.

Properties of study design

The choice of a suitable study design determines the scientific quality.

What follows in Lecture 03

A question and answers

Why conduct experiments?

Additional topic

Variance as a basic concept

...and another thing

Properties of measuring instruments

Table of contents

Appendix

Deductive vs. inductive

Deductive / deduction	Inductive / induction
Deduction is the process of making a general observation and drawing conclusions in the form of a specific finding; in empirical social research, it means drawing conclusions based on theories and then applying them to empirical data as predicted by the theory. In deductive reasoning, the cognitive process begins with a theory from which empirically testable hypotheses are derived. If these hypotheses are refuted, the theory is challenged on the basis of data. If the hypotheses are not refuted, the theory is regarded as provisionally confirmed. The deductive-nomological* explanatory model serves to test theory in the quantitative paradigm of empirical social research.	Induction means drawing conclusions from specific findings and applying them to a general situation; in empirical social research, it means taking a conclusion derived from empirical data, applying it via individual observed cases to higher-ranking scientific theories that can be generalized to a range of cases. In the case of inductive reasoning, the inquiry starts with data, and findings are gradually derived from the data. In the case of induction, the aim is to arrive at and confirm new theories. The inductive approach has established itself especially in the qualitative paradigm of empirical social research.

*Nomology: Nomology is an approach that mainly seeks to explain previously recognized regularities and thus is in contrast to approaches that attempt to investigate and interpret from the individual case.
This is based on the assumption that reality can be better explained by general laws and therefore can also be controlled.
[German Wikipedia, translated by the author]

Example of operationalization

Operationalization

Example intelligence test: "Intelligence" can be understood intuitively, but can only be formulated theoretically. Therefore, intelligence is defined in theory as a so-called construct and its properties are described. When quantitative-empirical research is conducted, the question arises how the construct can be captured – after all, there is no measuring device for intelligence.

The operationalization of the construct intelligence creates an "instrument", which in the case of the intelligence test consists of a series of questions (items), which are combined in several so-called item batteries in a questionnaire.

The answers to the questions in the questionnaire are recorded and condensed as a "score", which makes a quantitative statement (Einstein is said to have had an IQ of 160 ...) and with which further calculations can be made.

The next question that arises is whether the operationalization has been successful: Does the questionnaire or the item batteries actually measure the construct derived in the theory?

The answer to this question is a number - or several - and is generally referred to as validity. The more valid an instrument is, the better it can measure the theoretically based construct.