

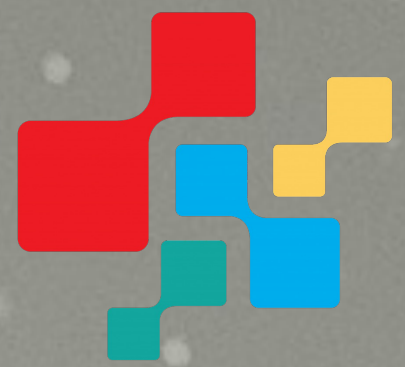
# Scientific method

193.052 **Seminar Wissenschaftliches Arbeiten**

Institut für Visual Computing & Human-Centered Technology (193)

Florian Michahelles

<http://media.tuwien.ac.at>

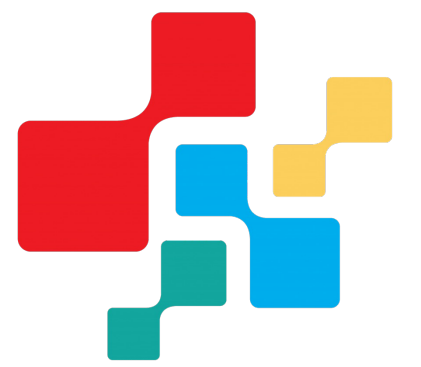


# Scientific method

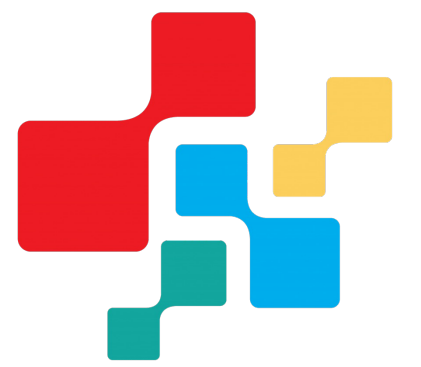
## Observation & Hypothesis

Florian Michahelles

# Goals of this video

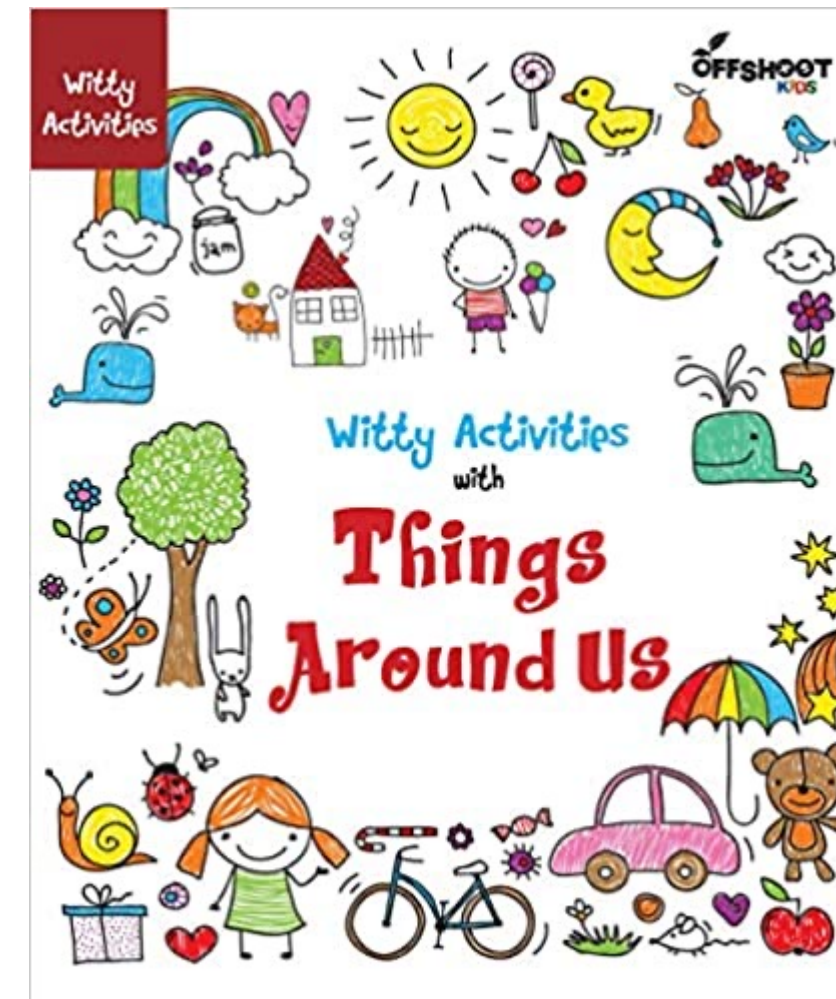


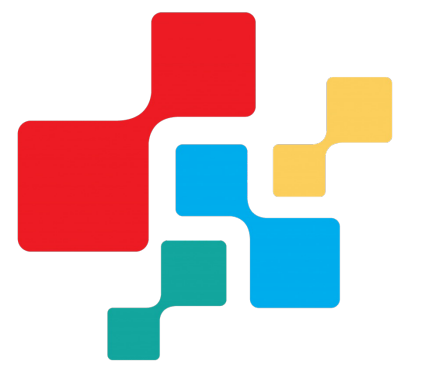
- Key concepts: observation, hypothesis, theory
- How to form clear, testable hypotheses
- Case study: Ignaz Semmelweiss child-birth fever explanation



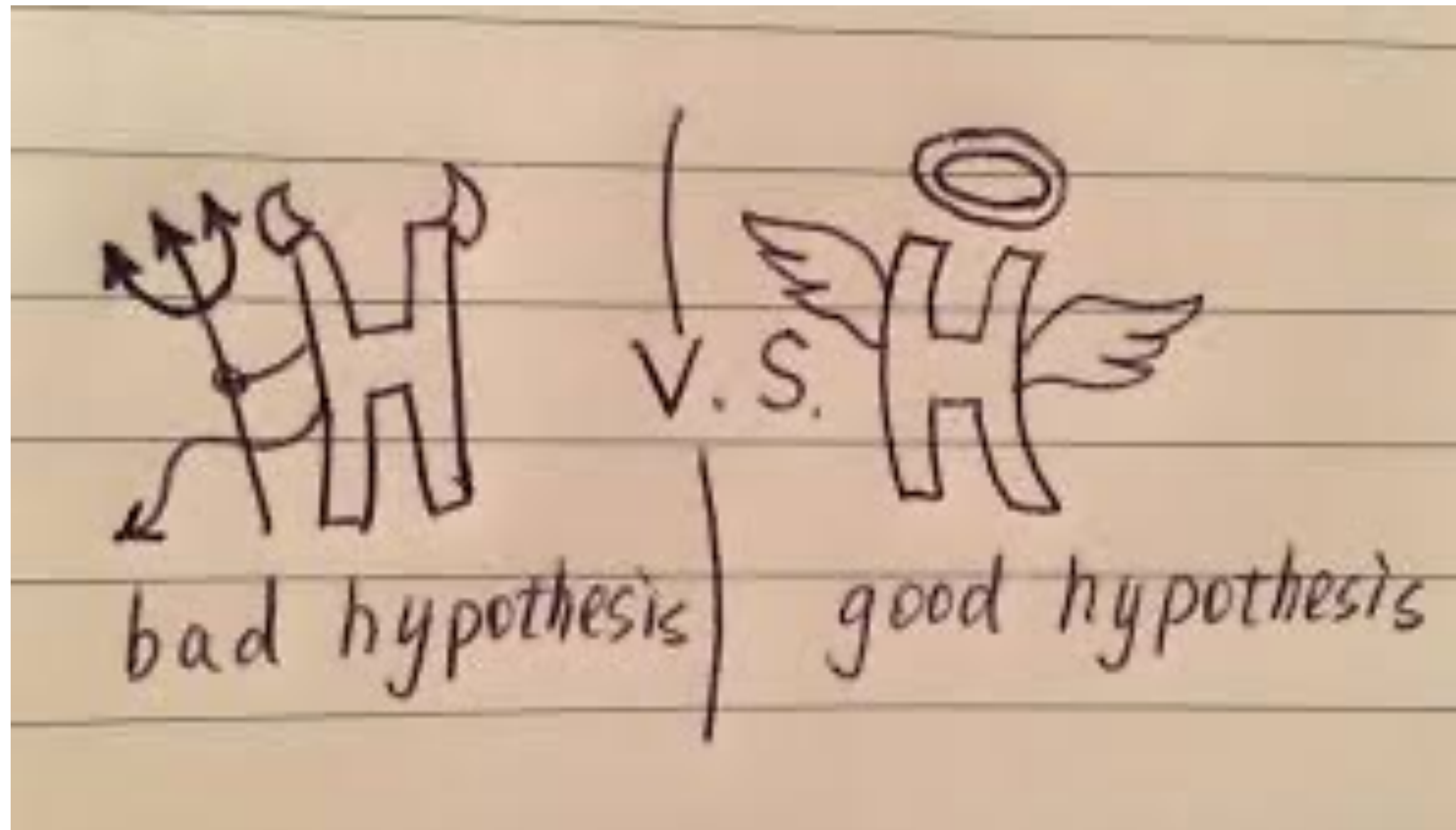
# Definitions: Observation $\rightarrow$ Hypothesis $\rightarrow$ Theory

- Observation: Systematic noticing of patterns
  - Algorithm slows down at large input sizes
- Hypothesis: A testable explanation of an observation
  - Cache miss rate increases with input size
- Theory: well developed explanation
  - In computing systems, as the size of the input data increases beyond the capacity of the cache, the likelihood of cache misses increases due to limited spatial and temporal locality. This leads to higher cache miss rates, particularly in systems with fixed-size cache architectures.

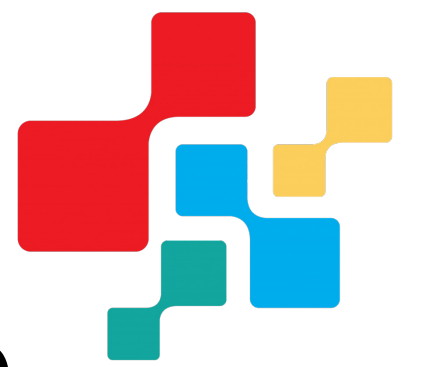




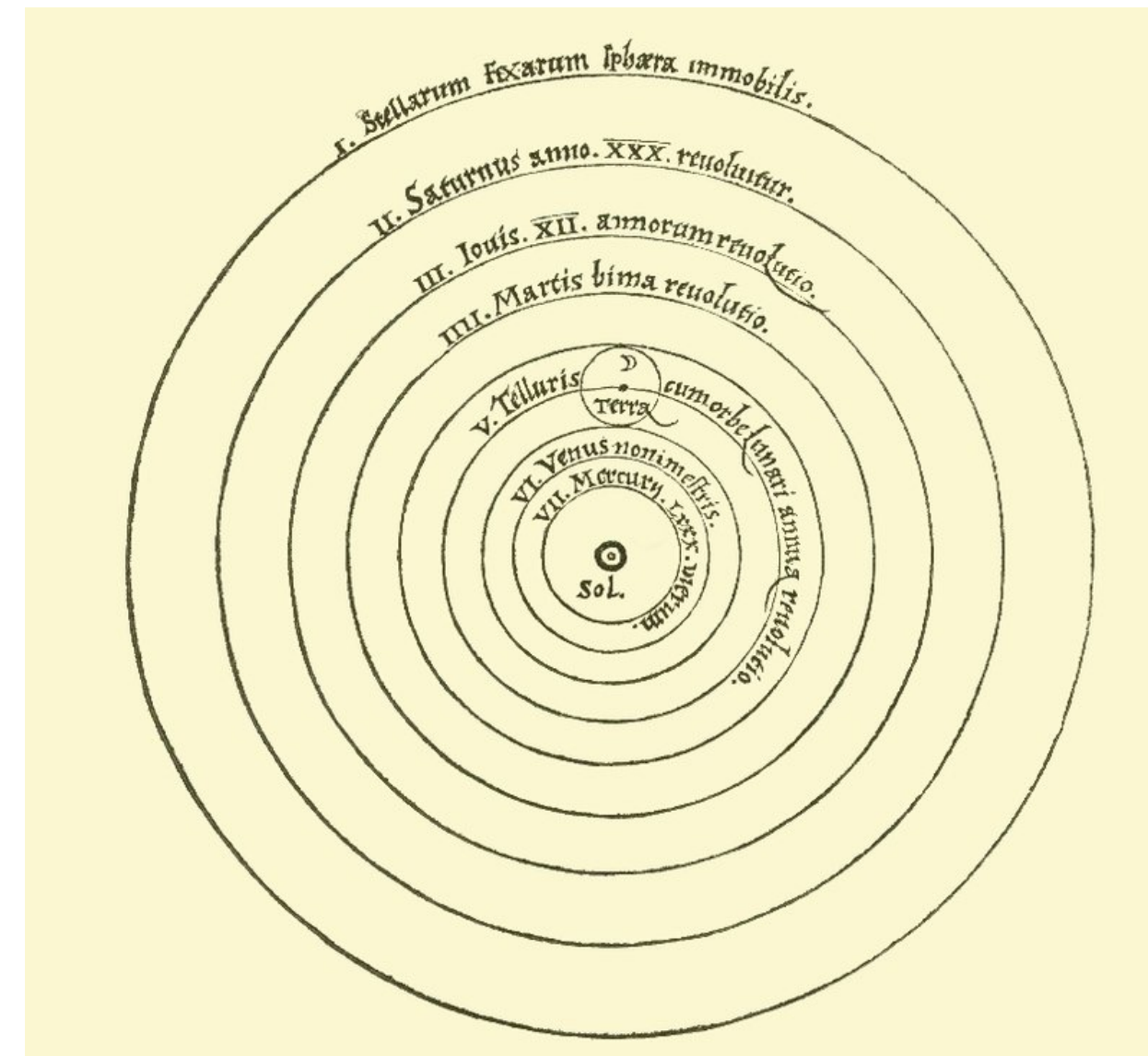
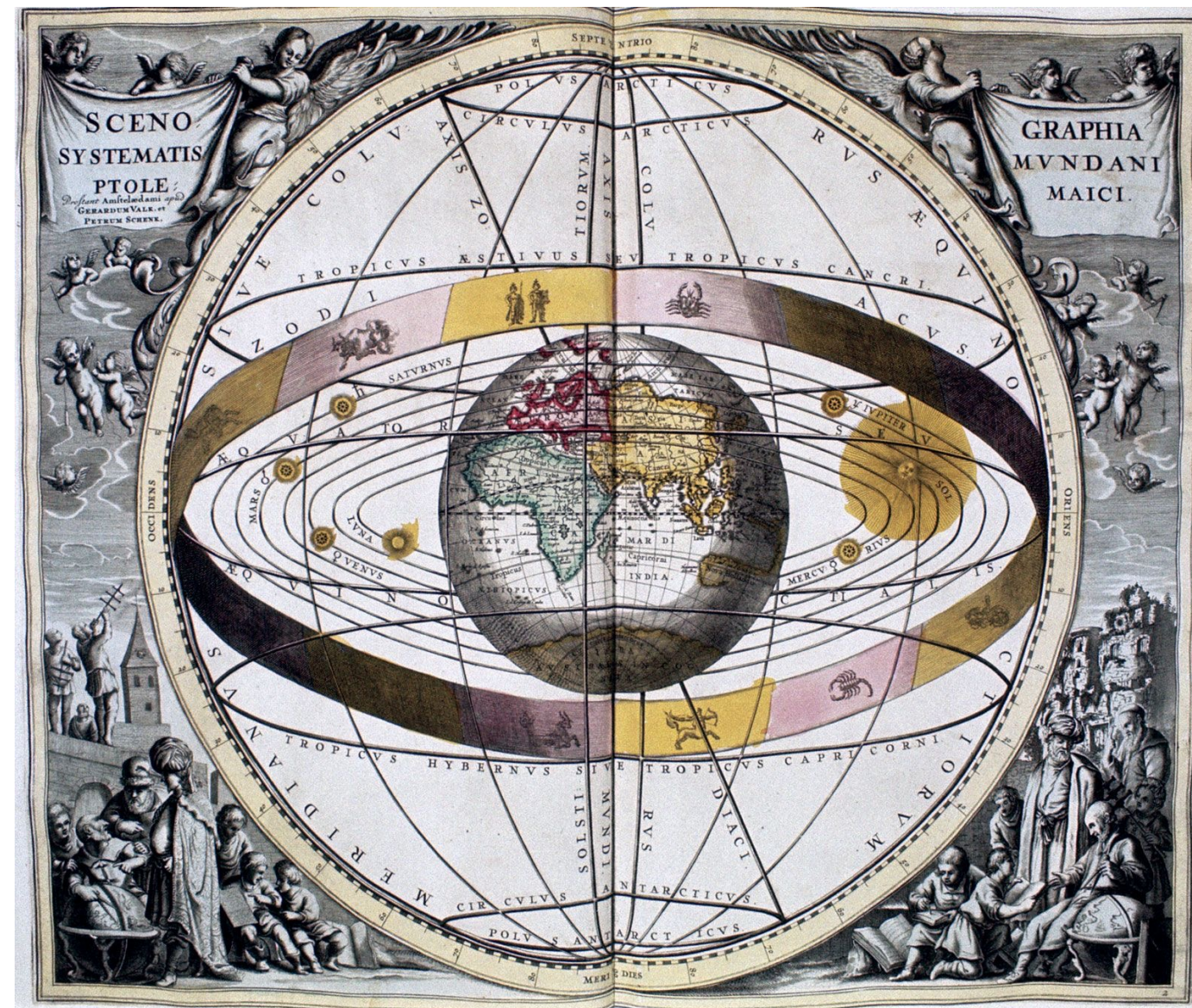
# Bad vs Good Hypotheses



<https://medium.com/@cherylcc/machine-learning-explained-with-funny-pictures-2-what-make-up-a-machine-learning-system-dd62c6abe3da>

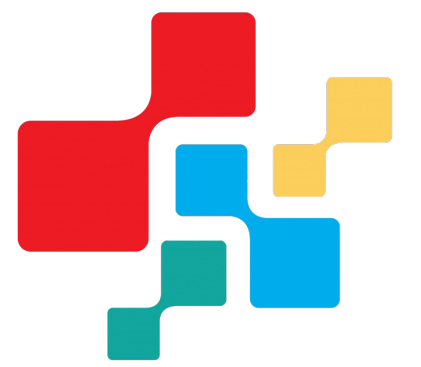


# Explanations: excursion - Ptolemy/Copernicus

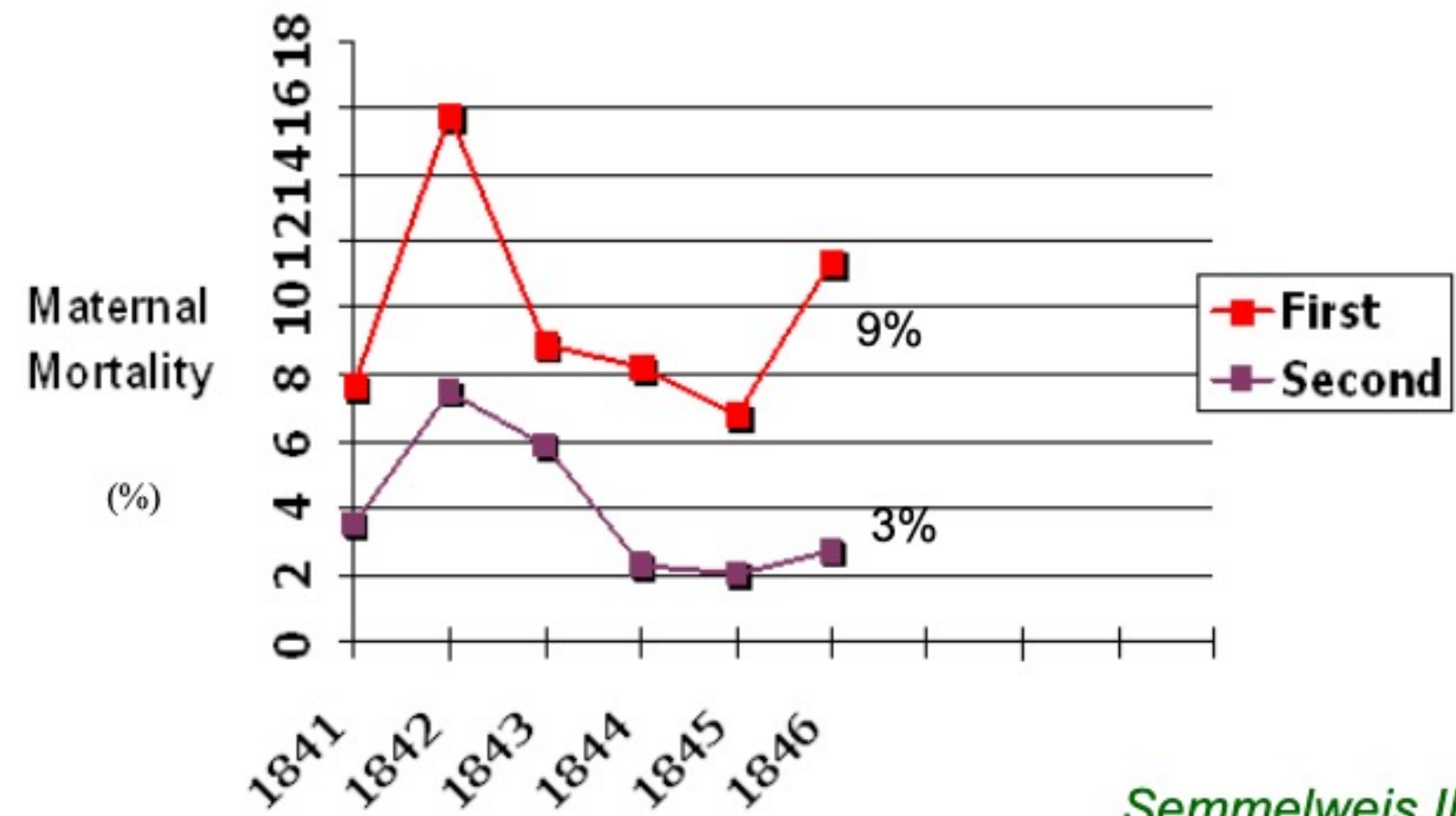
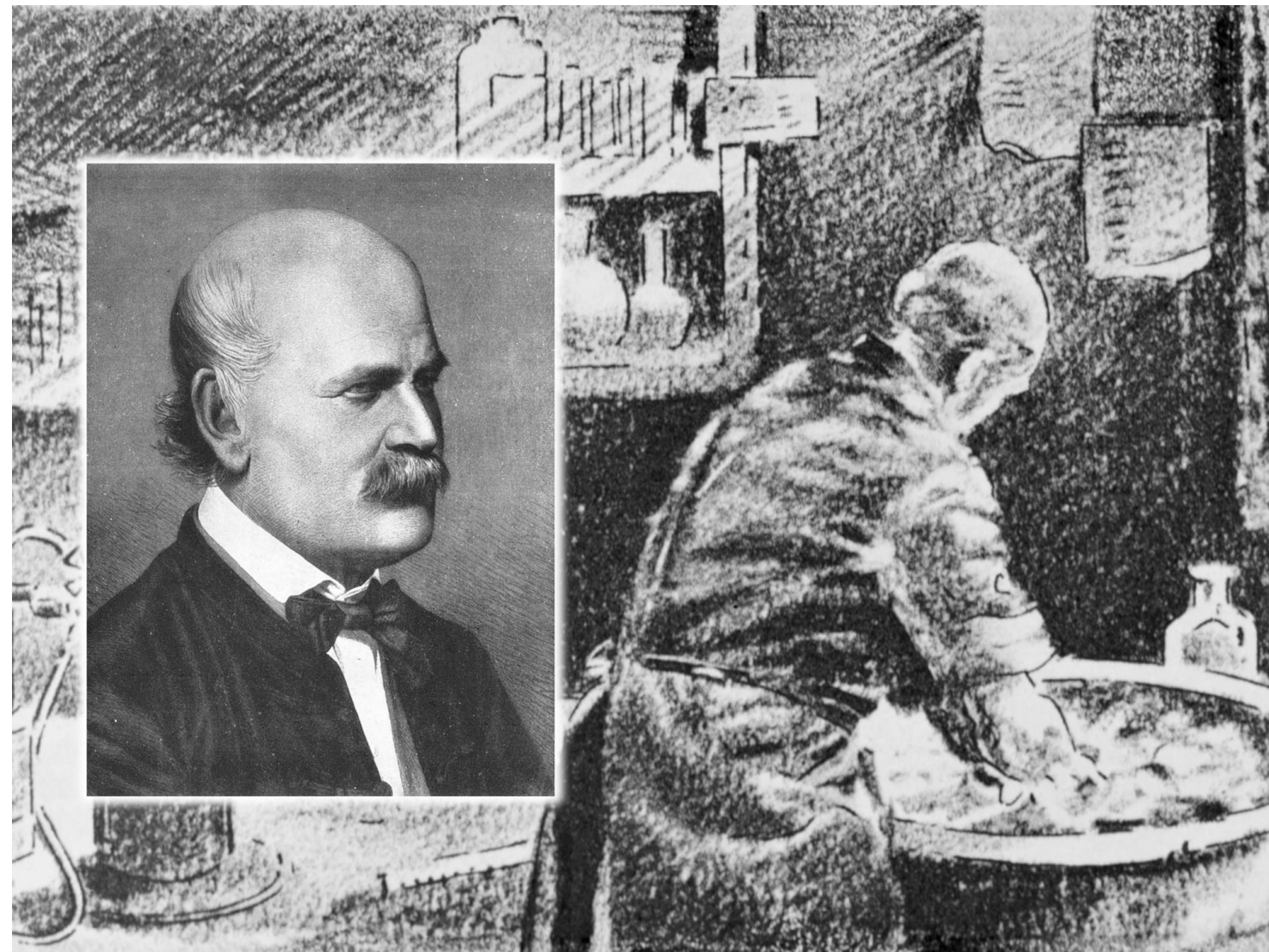


Photos.com/Thinkstock

[https://en.wikipedia.org/wiki/Copernican\\_heliocentrism](https://en.wikipedia.org/wiki/Copernican_heliocentrism)



# Ignaz Semmelweis: child-birth fever



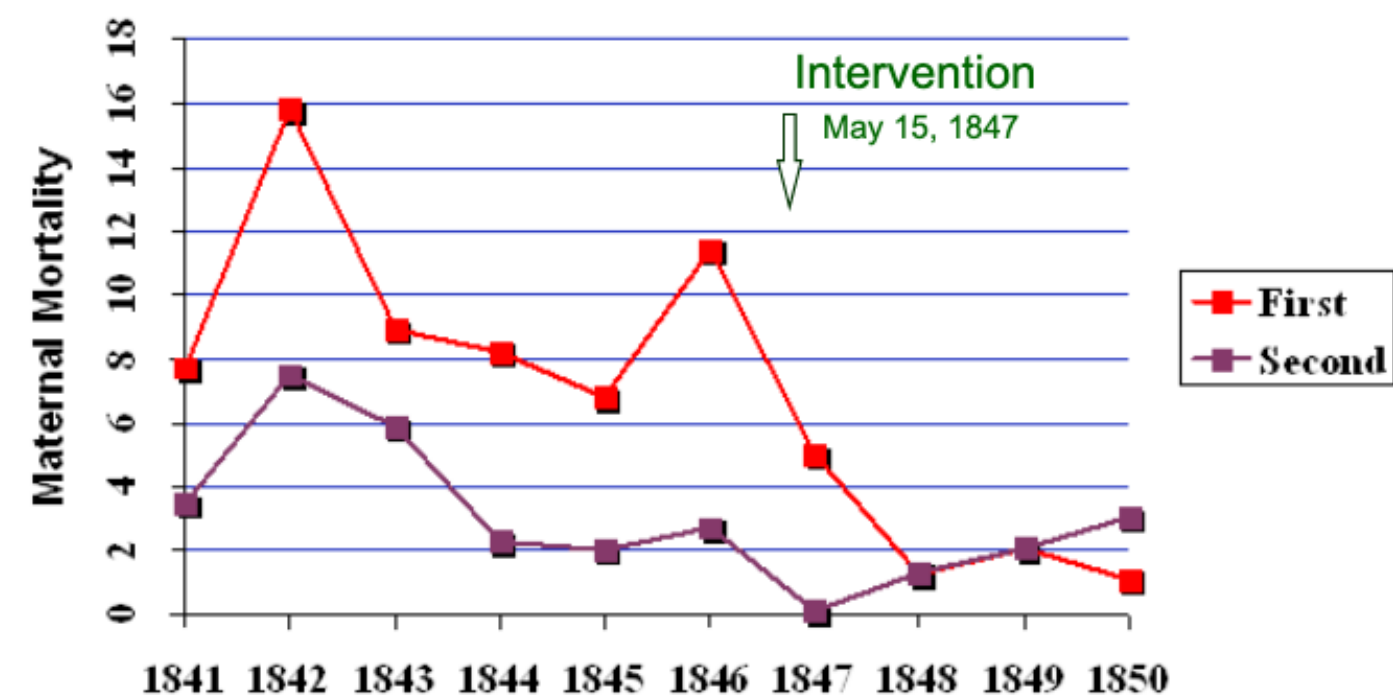
Semmelweis IP, 1861

<https://halfarsedhistory.net/2020/03/22/episode-91-the-tragedy-of-ignaz-semmelweis/>



*The working hypothesis is that the illness is transmitted by the students coming from the autopsies.*

– Semmelweis (Part 2, Scene 13)

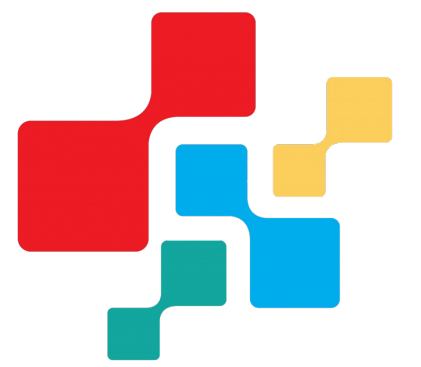


Semmelweis IP, 1861

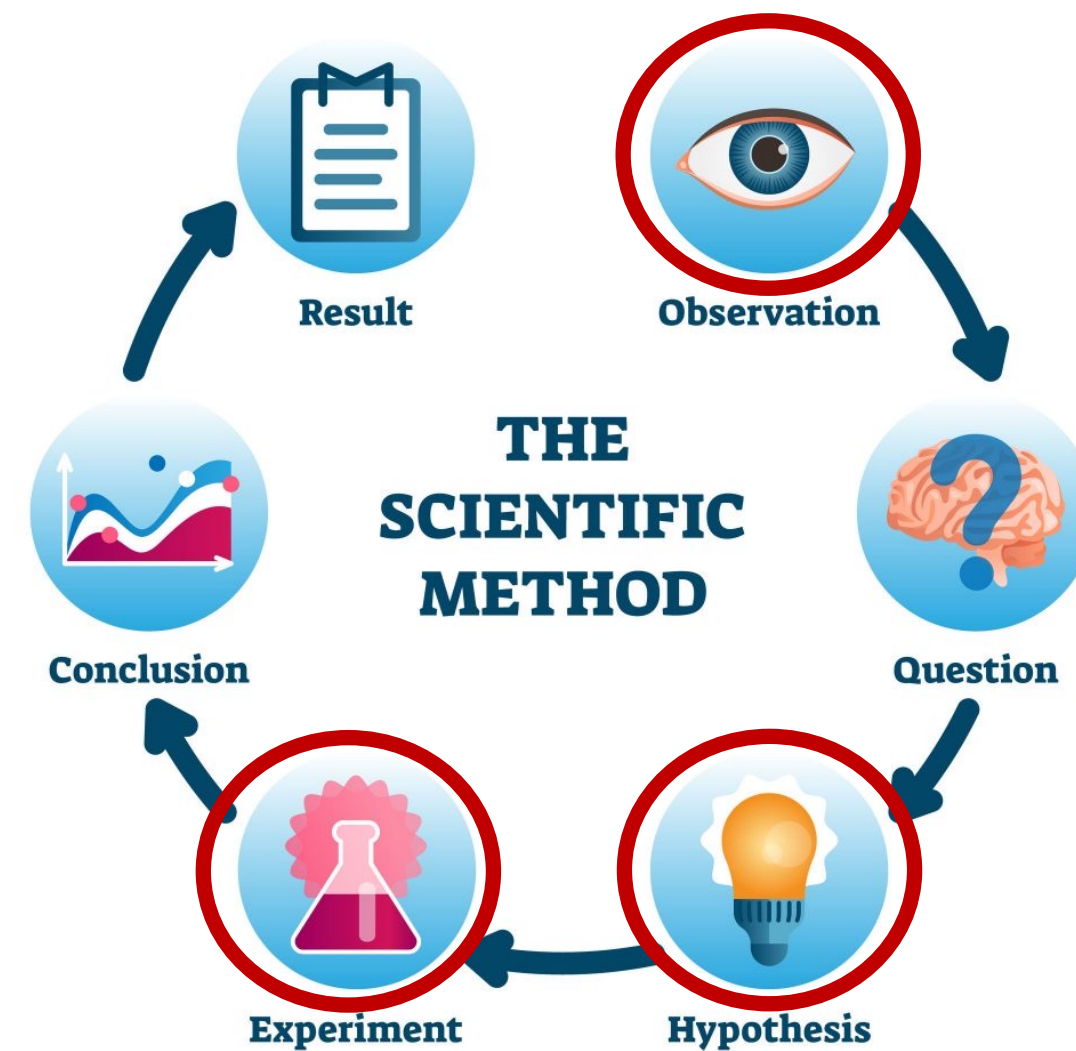
Pittet D, Boyce J. *Lancet Infect Dis* 2001;April :9-20

Contact: TUWEL





# The scientific method

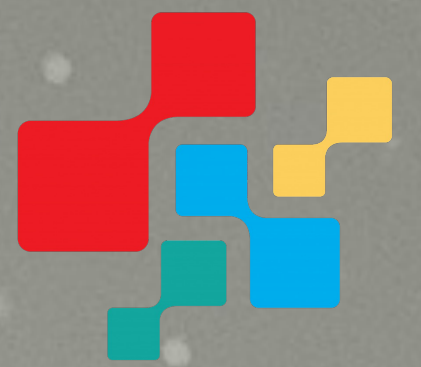


<https://www.australianenvironmentaleducation.com.au/education-resources/what-is-the-scientific-method/>

- Science is that activity, the underlying aim of which is to further our **understanding of why things happen** as they do in the natural world.
- It accomplished this goal by applications of the scientific method – the process of **observing** nature, **isolating** a facet that is not well understood, and then **proposing and testing possible explanations**.

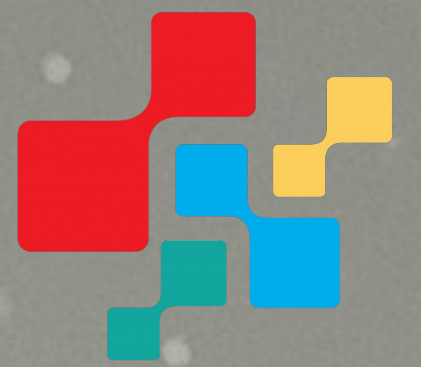


# Summary



- patterns of anomaly (observation)
  - > testable explanation (hypothesis)
  - > grounded explanation (theory)
- hypotheses must be specific and testable
- science is the practice of systematically observing the world





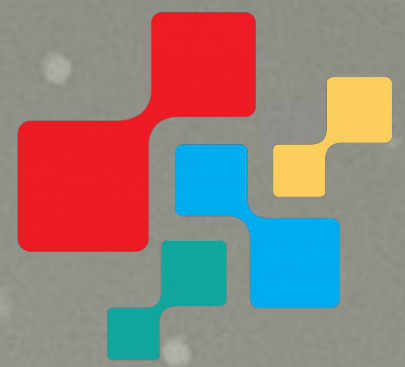
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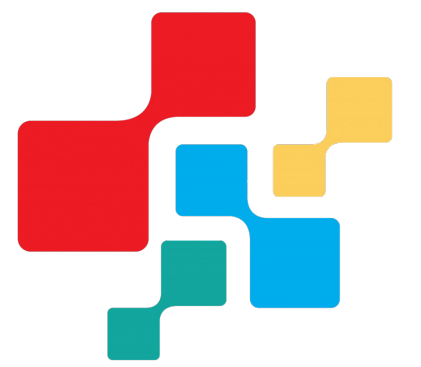


# Scientific method

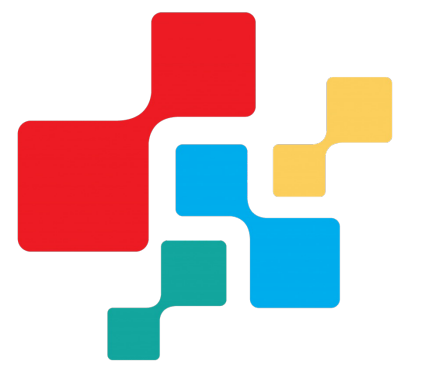
# Experiments & Testing

Florian Michahelles

# Goals of this video



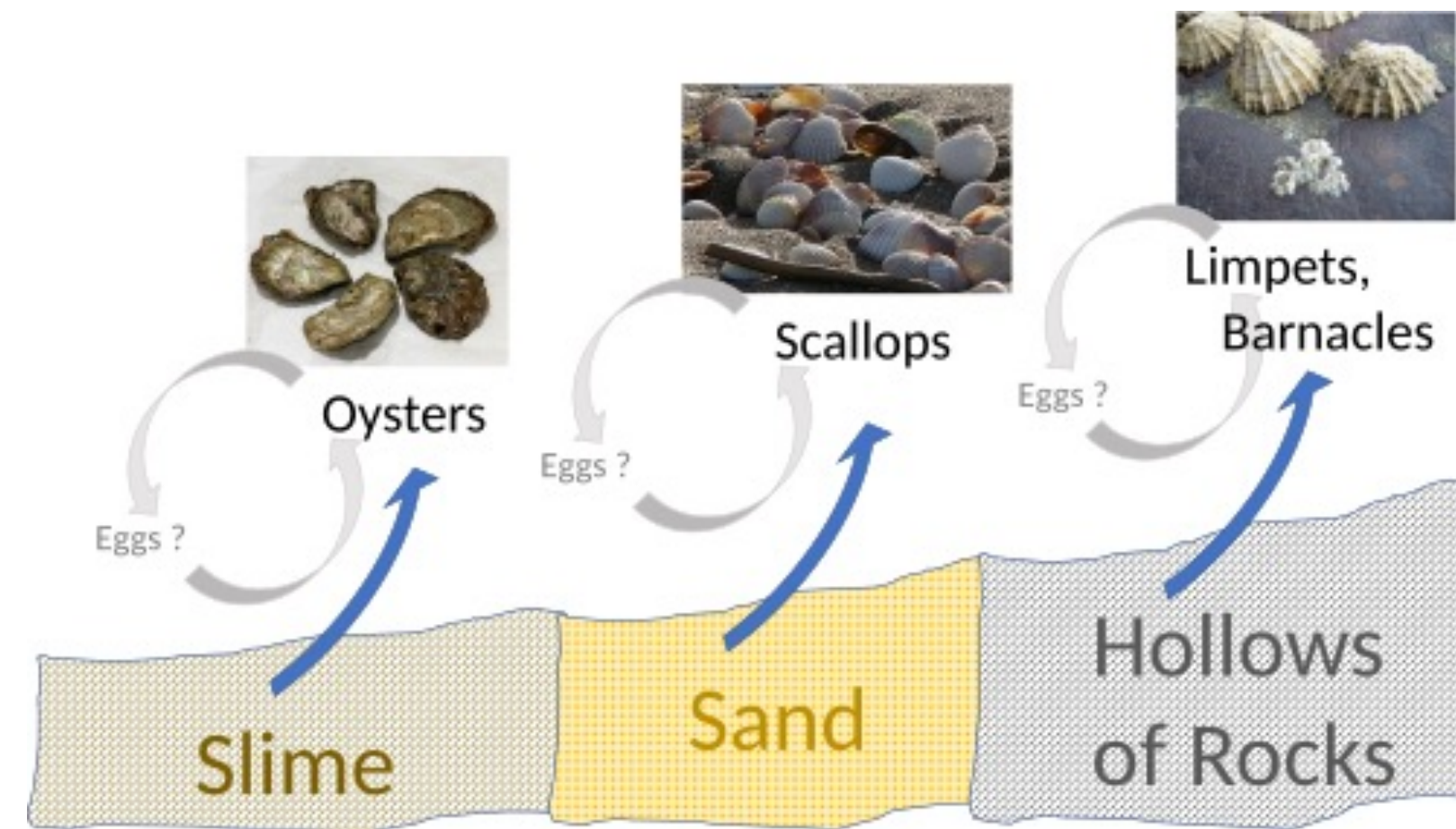
- Experimentation tests hypotheses under controlled conditions
- Decisive test
- Causation
- Bias



# Experiment: testing explanations



[https://en.wikipedia.org/wiki/Francesco\\_Red](https://en.wikipedia.org/wiki/Francesco_Red)



[https://en.wikipedia.org/wiki/Spontaneous\\_generation](https://en.wikipedia.org/wiki/Spontaneous_generation)

## REDI'S EXPERIMENT



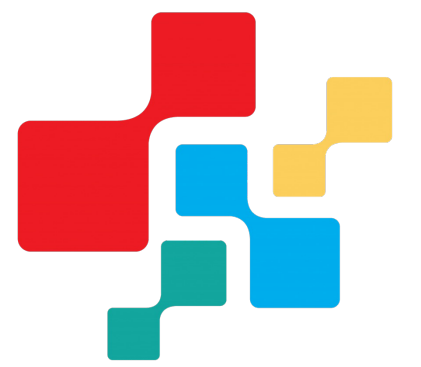
open jar



gauze-covered jar



sealed jar

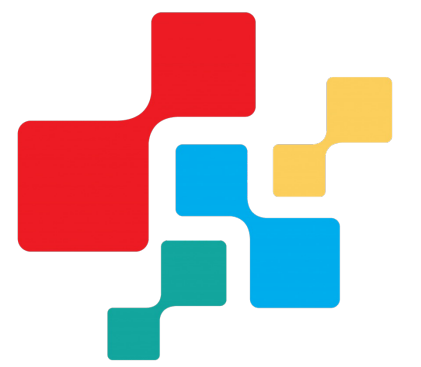


# Testing: requirements

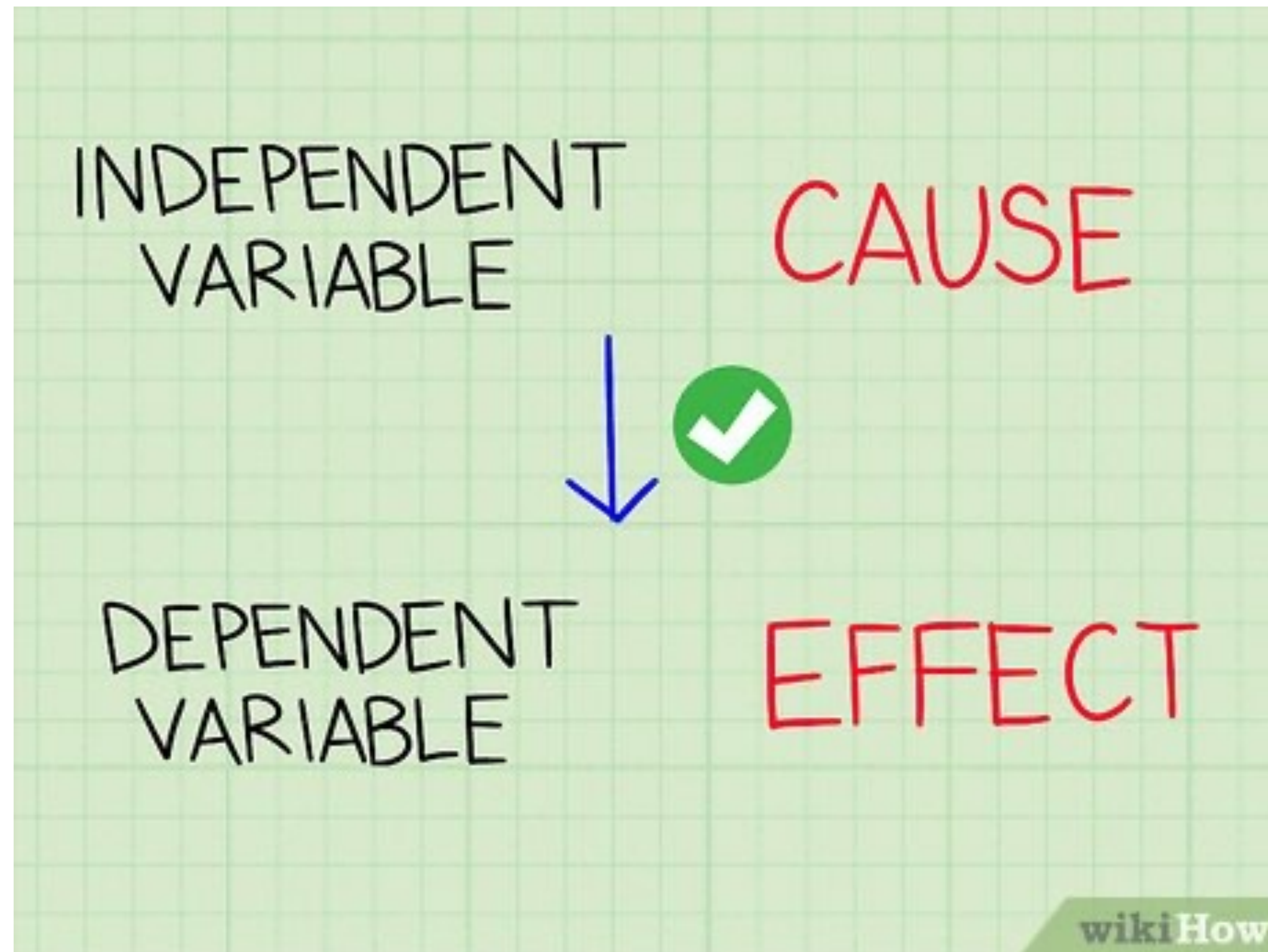
- falsifiability criterion
  - **your experiment needs to be able prove wrong.**
- verifiability criterion
  - **there is no other reason for the observation than your prediction**



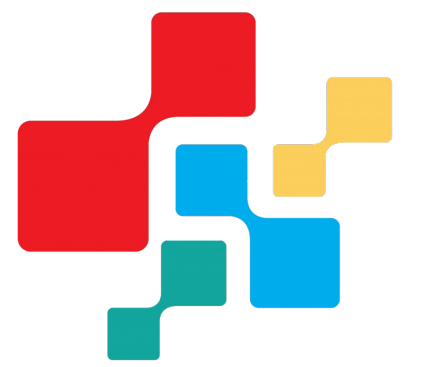
→ experiment was controlled, reproducible, and provided empirical evidence



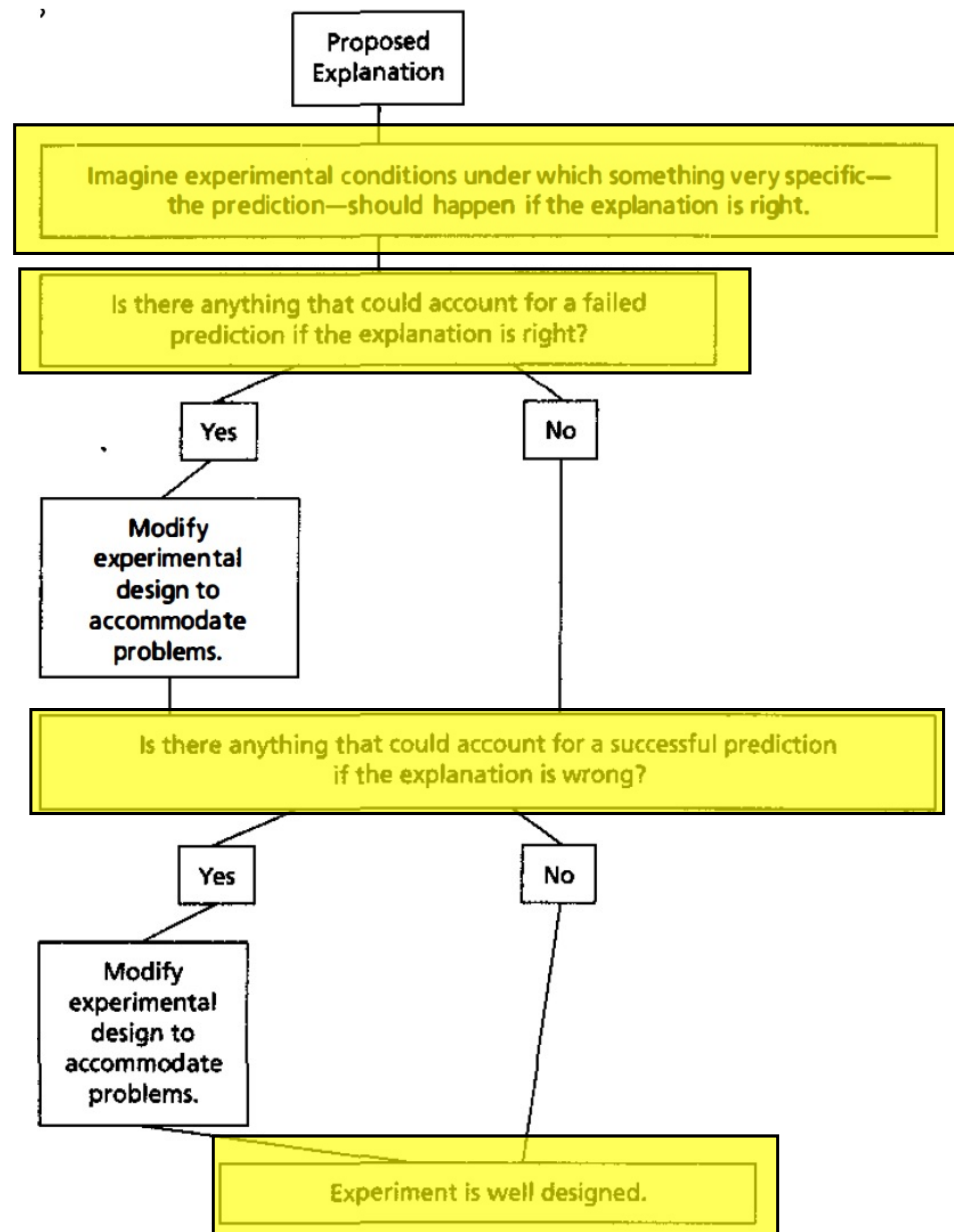
# Variables and Control



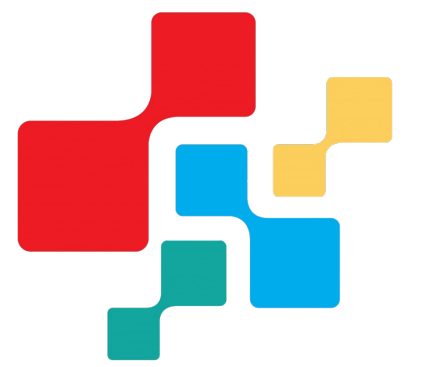
<https://www.wikihow.com/Identify-Dependent-and-Independent-Variables>



# Designing a decisive test

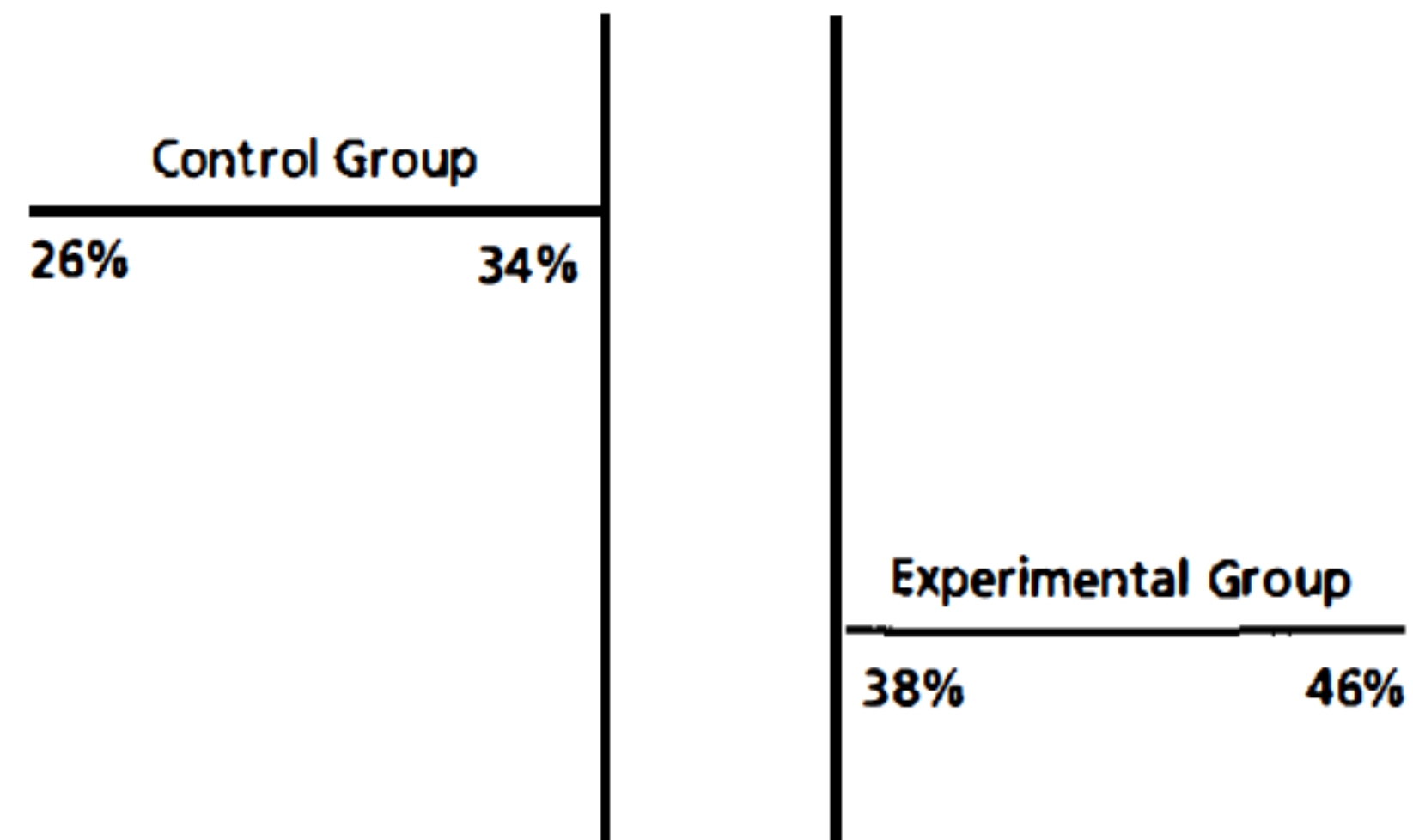


- isolate a prediction that will occur if an explanation is correct
- arrange circumstance in lab conditions or in the real world by checking the prediction against facts
- the prediction must be able to reject the explanation if it is wrong and confirm if it is correct.
  1. rule out factors that could account for predictive failure if the explanation is correct (falsifiability, e.g. perfect seals)
  2. rule out factors that could explain predictive success even if the explanation is wrong (verifiability, e.g. active principle of air)
- It is rare for a big idea in science to be verified or falsified by the results of a single experiment.

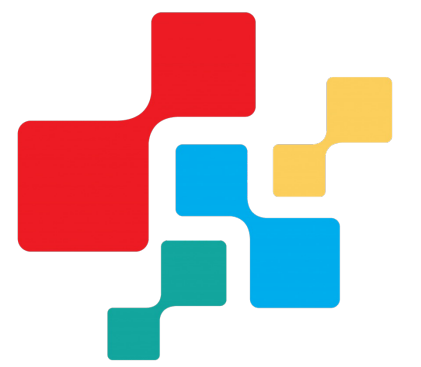


# Establishing causal links

- ◉ Null hypothesis: there is an effect
- ◉ significance:

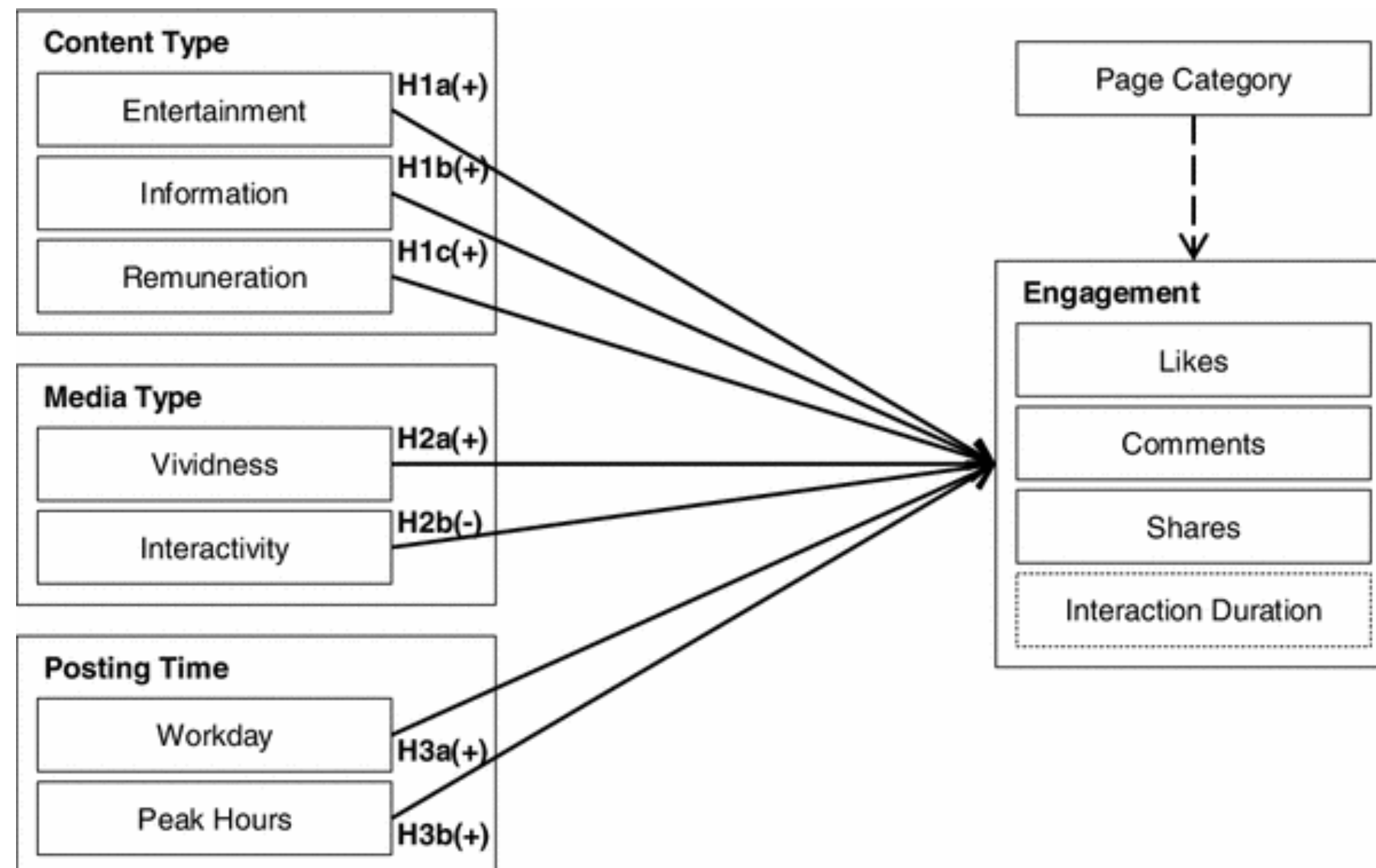


- ◉ statistically significant:  $p < 0,05$ 
  - ◉ 95% chance of difference between samples

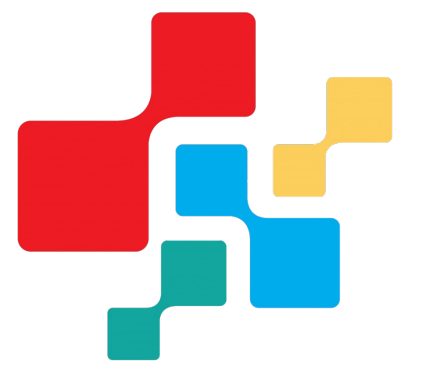


# Multiple causal links form explanations

- ◉ explanations rarely come to an end: chain of explanations
- ◉ example: effects in facebook

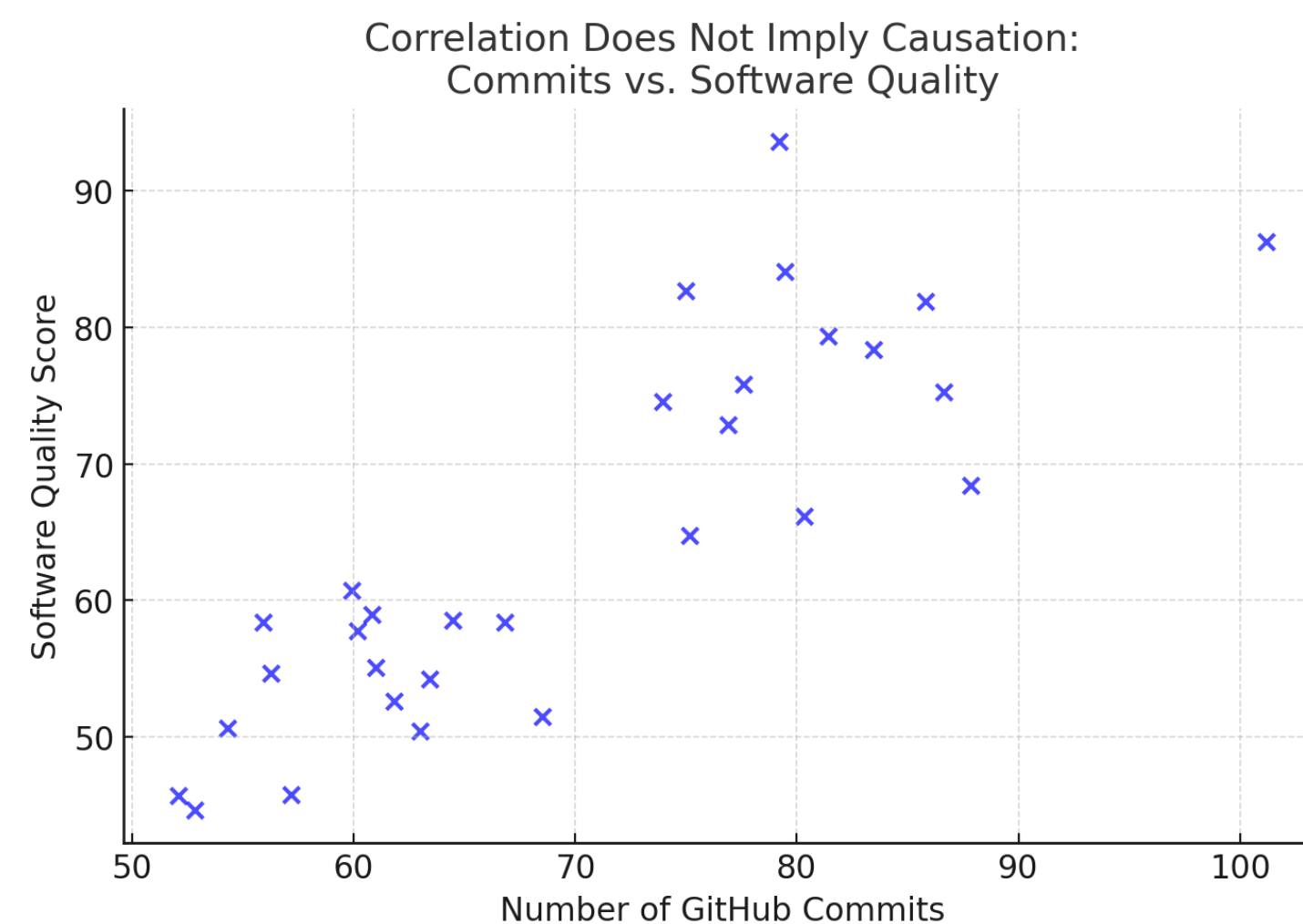
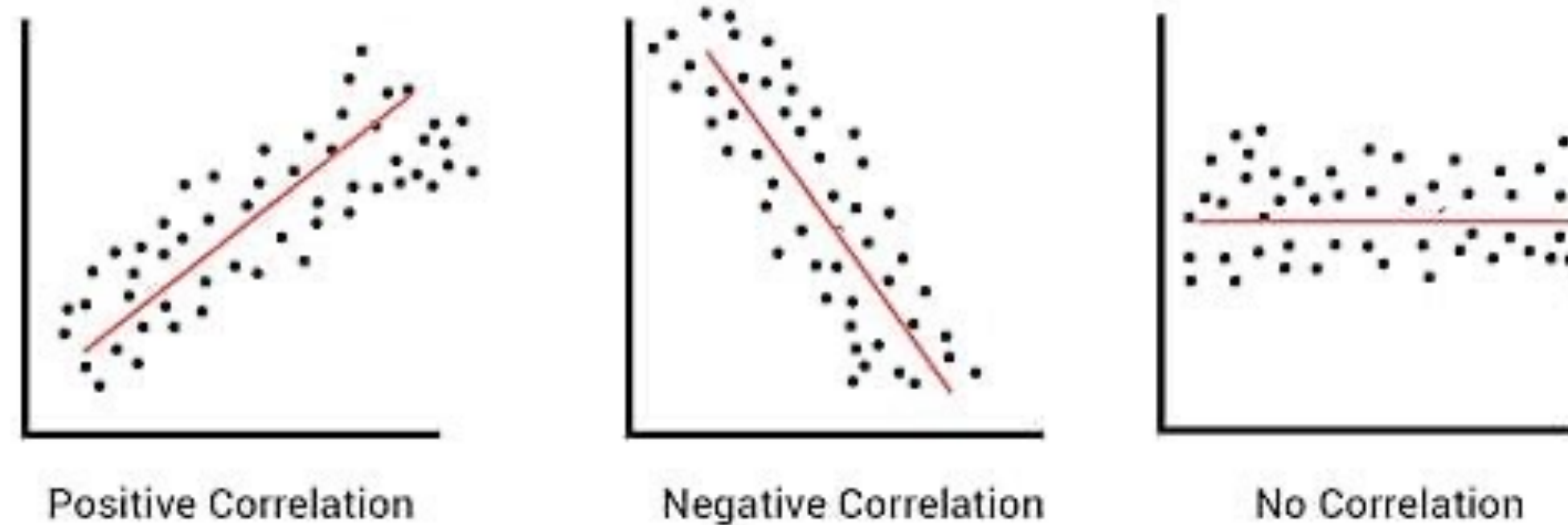


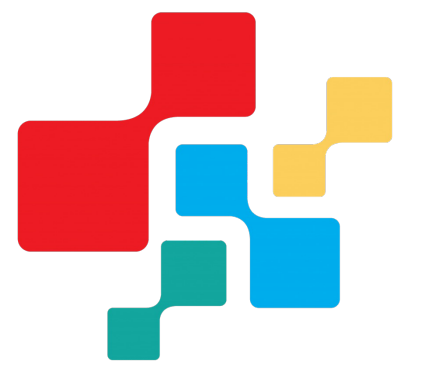
Pletikosa Cvijikj, Irena, and Florian Michahelles. "Online engagement factors on Facebook brand pages." *Social network analysis and mining* 3.4 (2013): 843-861.



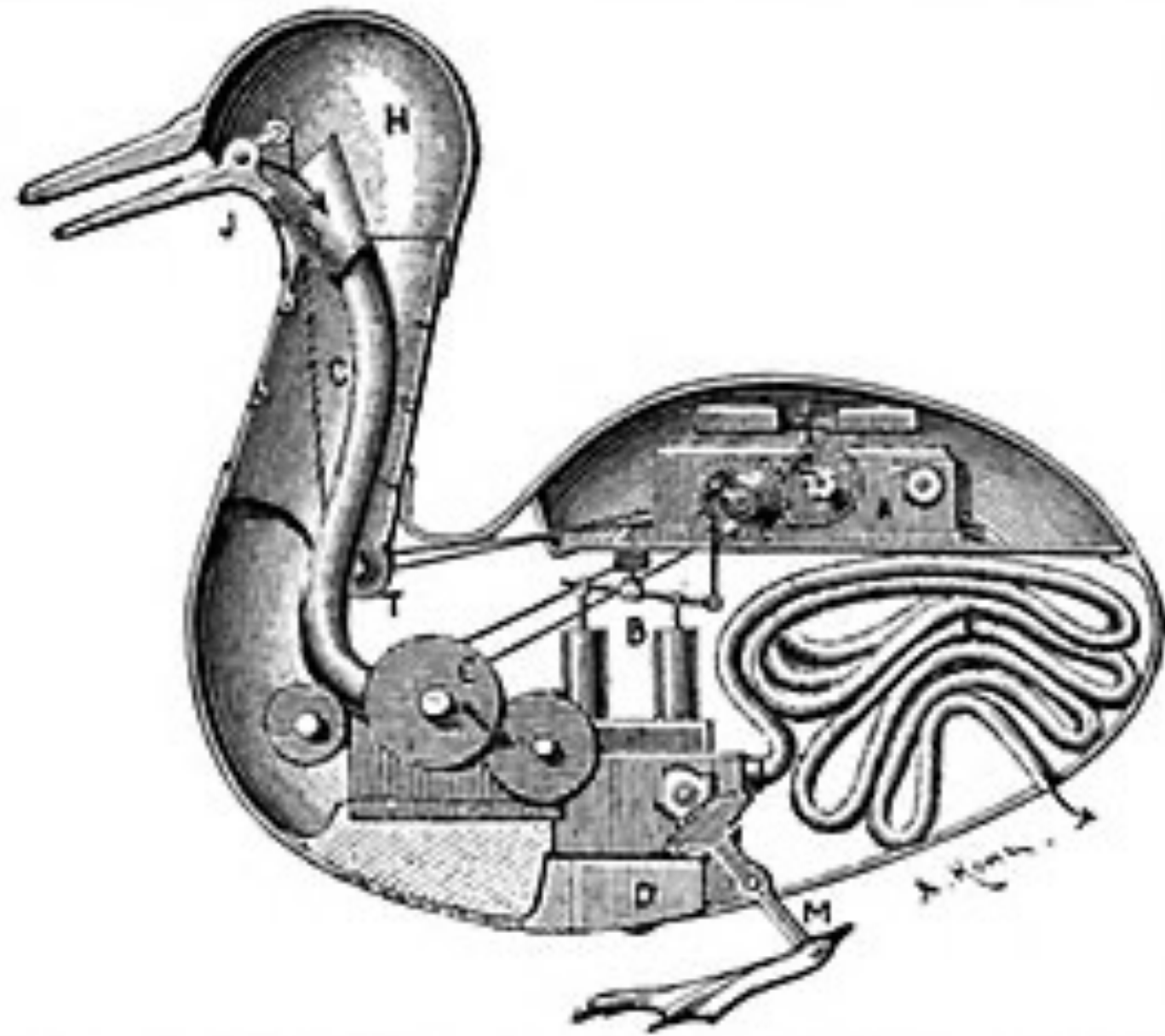
# Explanations: correlation

- ◉ degree to which a pair of variables are linearly related

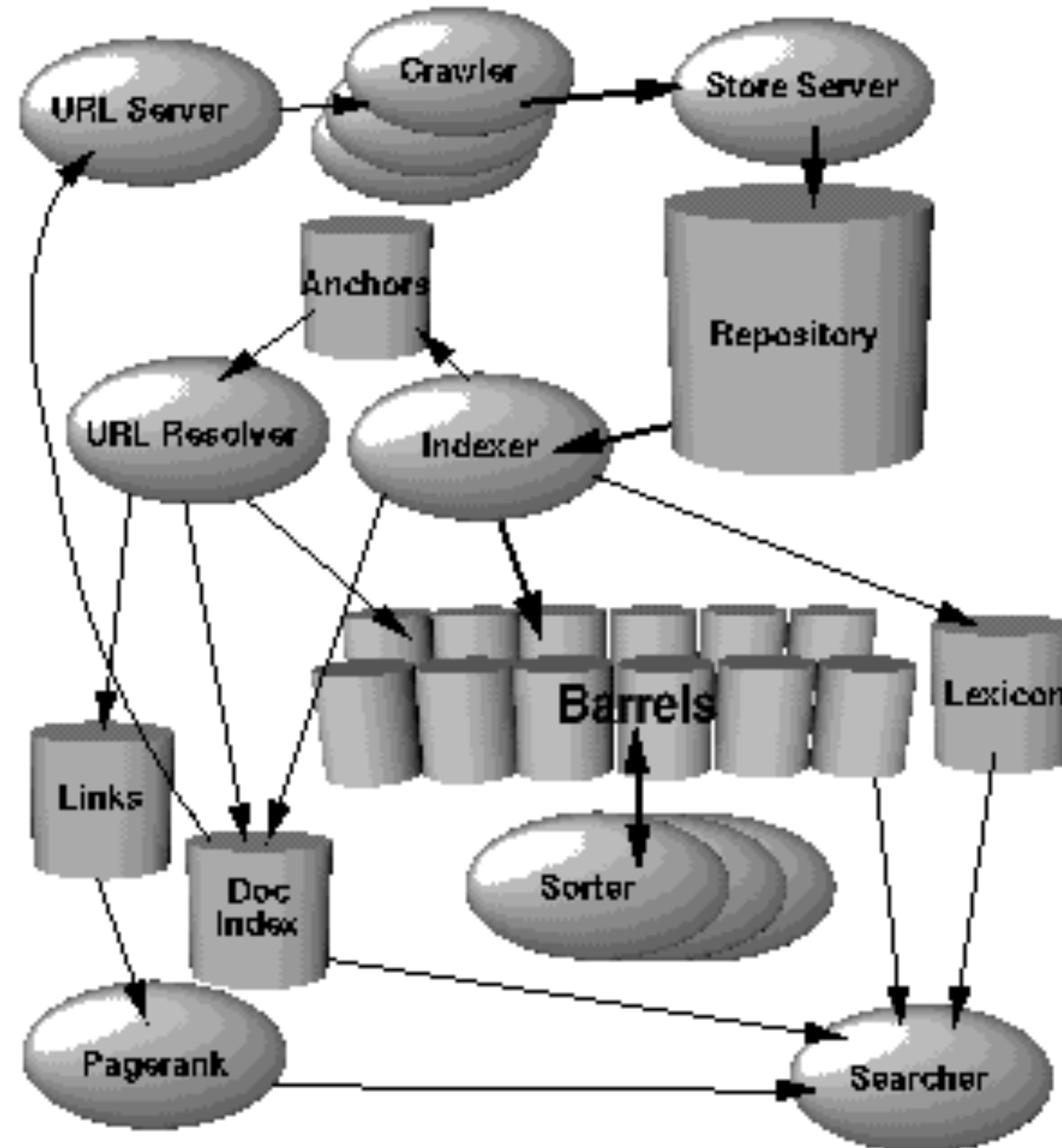




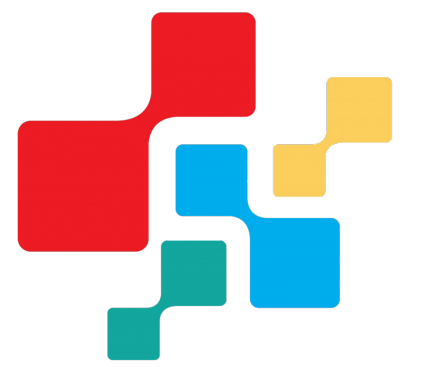
# Underlying process



**INTERIOR OF VAUCANSON'S AUTOMATIC DUCK.**  
A, clockwork; B, pump; C, mill for grinding grain; E, intestinal tube;  
J, bill; H, head; M, feet.



Sergey Brin, Lawrence Page,  
The anatomy of a large-scale hypertextual Web search engine,  
Computer Networks and ISDN Systems, Volume 30, Issues 1-7, 1998, Pages 107-117, [https://doi.org/10.1016/S0169-7552\(98\)00110-X](https://doi.org/10.1016/S0169-7552(98)00110-X)



# Bias and expectation

- ◉ Control of causal factors
- ◉ Experimenter bias
- ◉ Experimental subject expectations
- ◉ Statistical significance



# Summary



- Falsifiability & Verifiability
- Independent & dependent variables
- Decisive Test
- Causality & Correlation
- Underlying process
- Bias





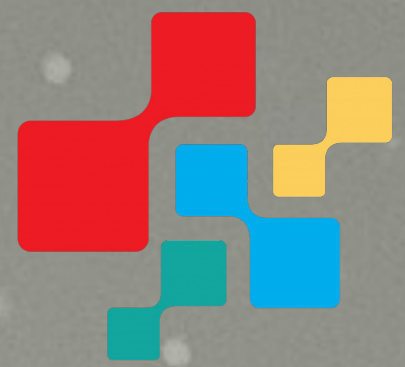
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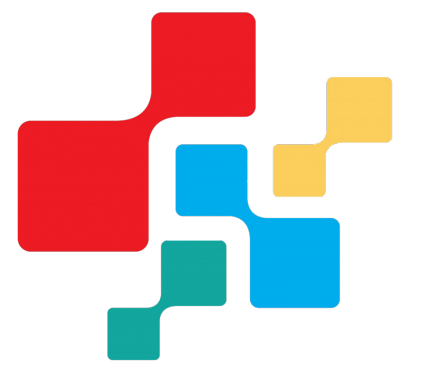


# Scientific method

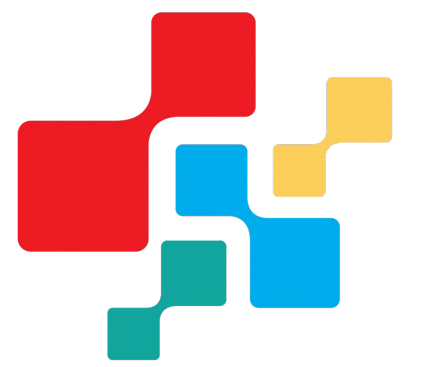
# Theories, Models, and Paradigms

Florian Michahelles

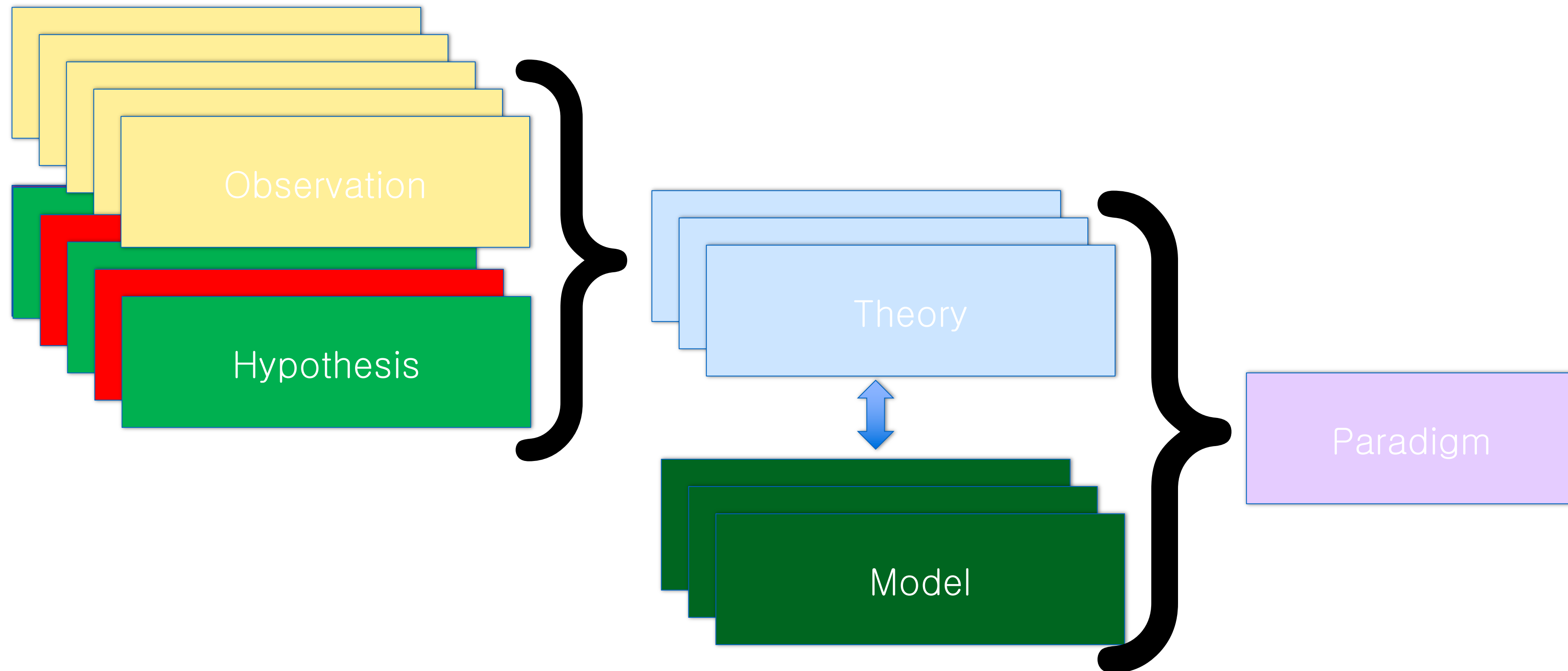
# Goals of this video

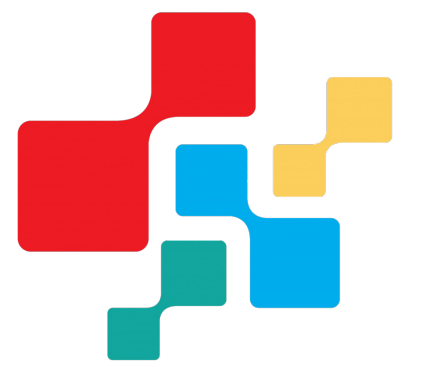


- ◉ how paradigms evolve and build upon theories
- ◉ the paradigm of design science



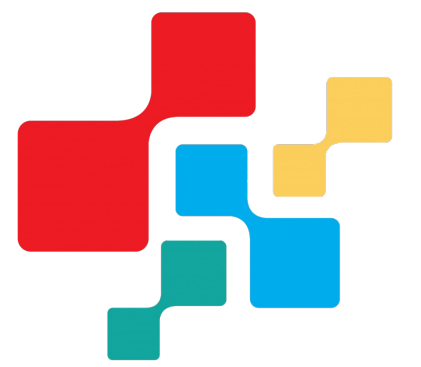
# How paradigms evolve



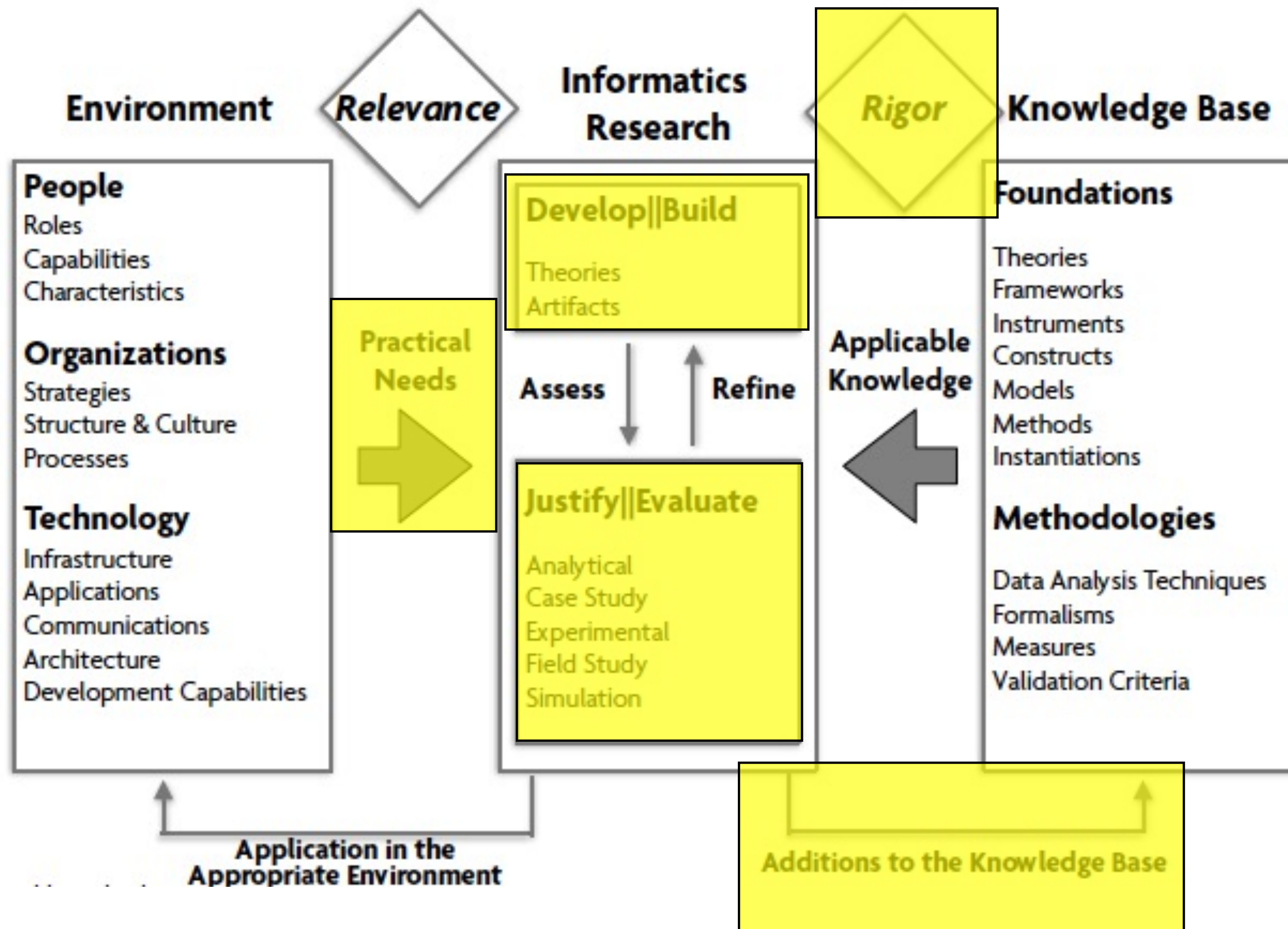


# Model, theory, paradigm

Feature	Theory	Model	Paradigm
<b>Purpose</b>	Explains why	Describes/predicts how	set of beliefs and assumptions that a particular field or phenomenon
<b>Abstraction level</b>	High	Medium to low	Very high
<b>Testability</b>	Indirectly testable via hypotheses	Directly testable	Not testable
<b>Example Use</b>	Understanding general principles	Simulating or predicting outcomes	defines the accepted methods, theories, standards, and types of questions considered valid within a scientific discipline
<b>Example</b>	<i>As input size grows beyond cache capacity, cache performance degrades due to reduced locality.</i>	<i>Cache Miss Model: A function that predicts cache miss rate based on input size and cache parameters, e.g., <math>\text{miss\_rate} = f(\text{input\_size}, \text{cache\_size})</math>.</i>	The Von Neumann architecture is a paradigm for how computers are structured and programmed.

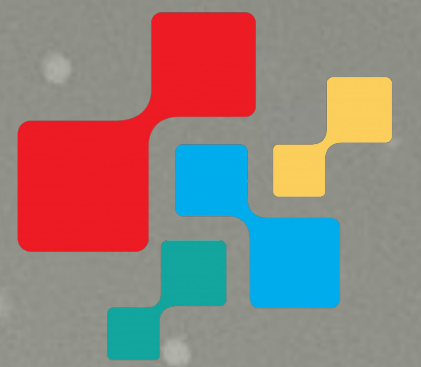


# Methods for Computer Science



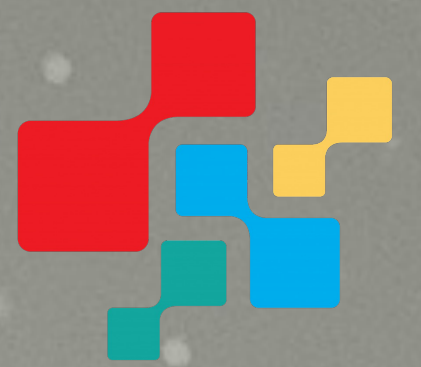


# Summary



- Observations lead to **hypotheses**, which are tested and refined.
- Consistent explanations form **theories** — deep, evidence-based understandings of how things work.
- **Models** simplify and represent these theories, making them easier to apply or simulate.
- **Paradigms** define the overarching worldview — the assumptions, values, and methods that guide an entire field.
- **Design science** has become an established research paradigm for connecting theory and practice through the creation and evaluation of purposeful artifacts.





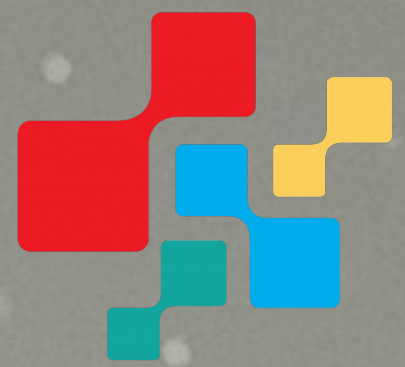
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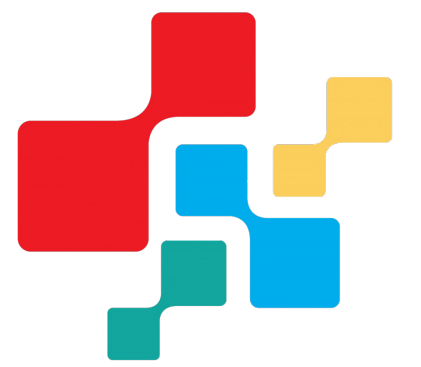


# Scientific method

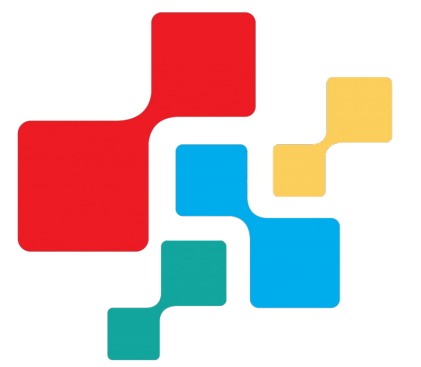
# Research methods

Florian Michahelles

# Goals of this video

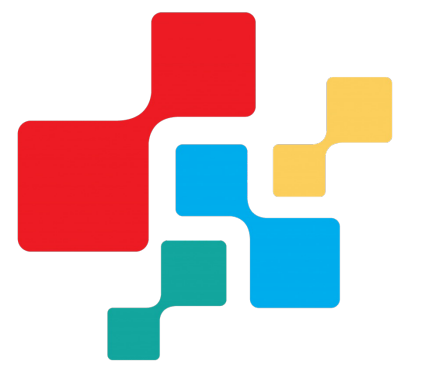


- Scientific Methods: Qualitative, Quantitative, Mixed
- Research Design and Planning
- Data Collection & Analysis Techniques
- Real-world Applications in Computing



# What Is the Scientific Method?

- ◉ Systematic process for generating knowledge
- ◉ Steps: Observe → Hypothesize → Test → Analyze → Conclude
  
- Quantitative: Objective, numeric data, statistics
- Qualitative: Contextual, descriptive, interpretive
- Mixed: Combines both to gain depth and breadth



# Quantitative Research

- Structured, measurable, generalizable
- Examples:



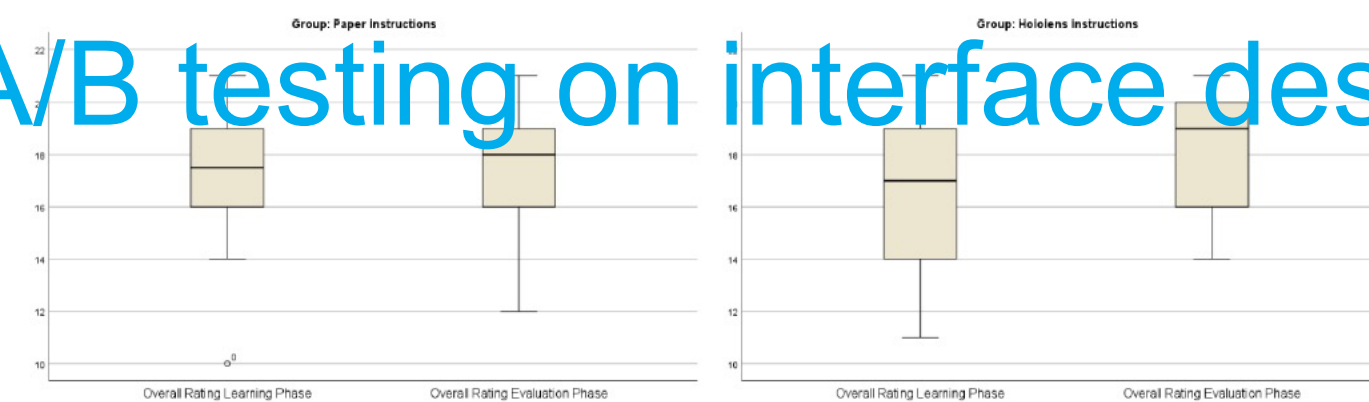
Michael Ungersböck, Thomas Hiessl, Daniel Schall, and Florian Michahelles. 2023. Explainable Federated Learning: A Lifecycle Dashboard for Industrial Settings. IEEE Pervasive Computing 22, 1 (Jan.-March 2023), 19-28. <https://doi.org/10.1109/MPRV.2022.3229166>

TAM (Bonferroni $\alpha = 0.01$ )	Items	Cronbach's $\alpha$
Perceived usefulness (PU)	3	0.698
Perceived ease of use (PEoU)	5	0.730
Attitude (Att)	5	0.694
Trust and Safety (trust)	4	0.778
Intention (Int)	1	NA

User survey ratings

mbika Shahu, Philipp Wintersberger, and Florian Michahelles. 2022. Scenario-based Investigation of Acceptance of Electric Muscle Stimulation. In Proceedings of the Augmented Humans International Conference 2022 (AHs '22). Association for Computing Machinery, New York, NY, USA, 184-194. <https://doi.org/10.1145/3519391.3519416>

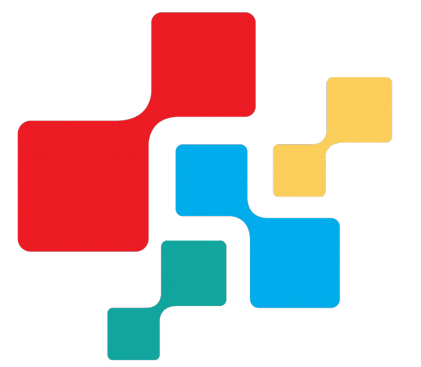
A/B testing on interface design



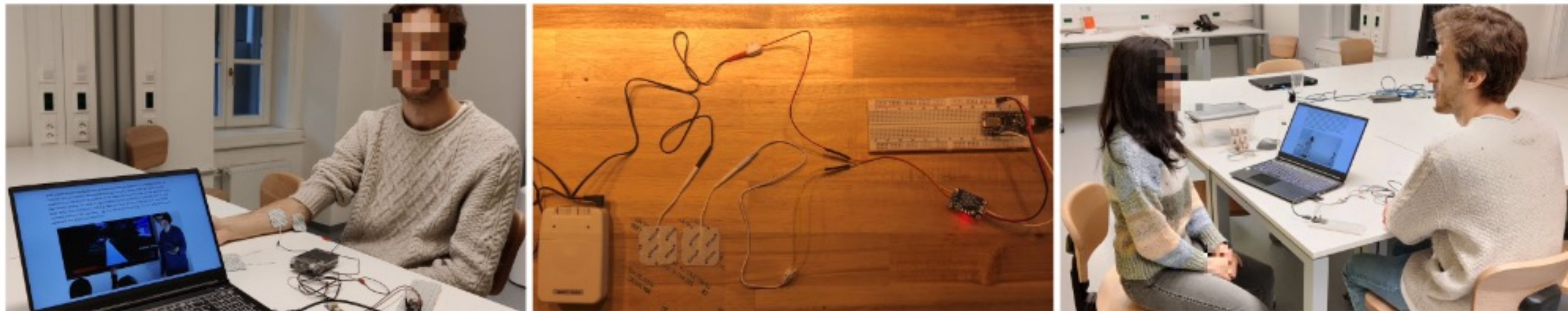
(a) Learning and Evaluation phase score for paper instructions (b) Learning and Evaluation phase score for Skillab

Shahu, A., Dorfbauer, S., Wintersberger, P., Michahelles, F. (2023). Skillab - A Multimodal Augmented Reality Environment for Learning Manual Tasks. In: Abdelnour Nocera, J., Kristin Lárusdóttir, M., Petrie, H., Piccinno, A., Winckler, M. (eds) Human-Computer Interaction - INTERACT 2023. INTERACT 2023. Lecture Notes in Computer Science, vol 14144. Springer, Cham. [https://doi.org/10.1007/978-3-031-42286-7\\_33](https://doi.org/10.1007/978-3-031-42286-7_33)

- Methods: Experiments, surveys, log analysis

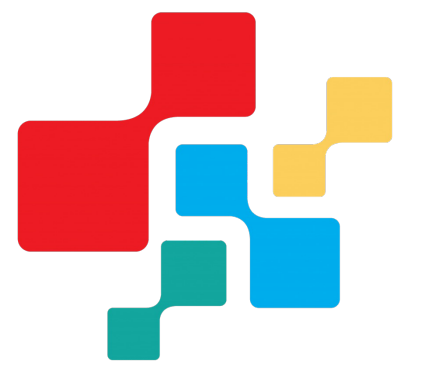


# Qualitative Research

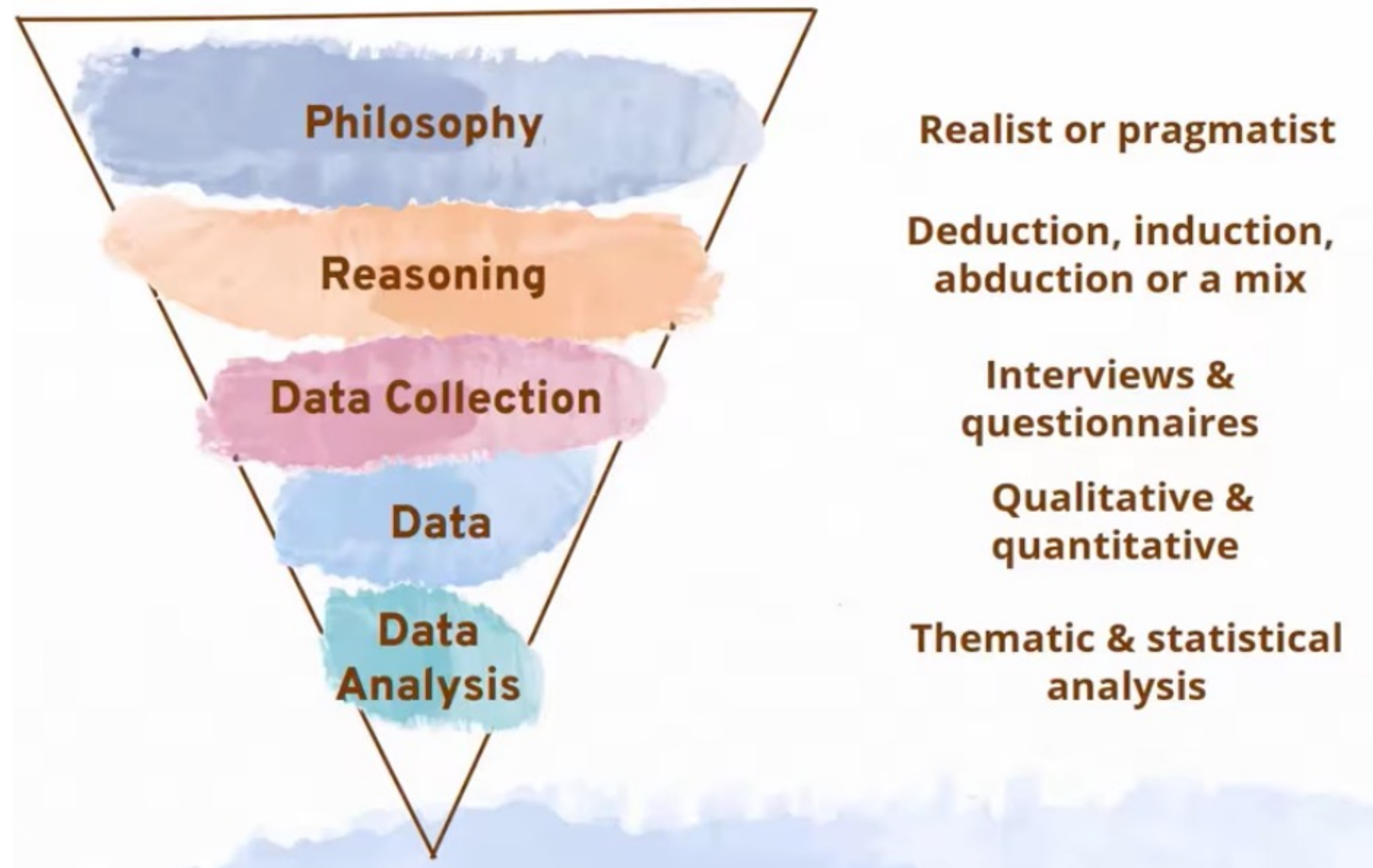


Immersiveness	Aiding skill building	New and fascinating	Diverse range of applications
<ul style="list-style-type: none"><li>It's very immersive, it's like you're really there.</li><li>You get a better feedback in VR.</li><li>I would use it if it's adding up to my experience.</li></ul>	<ul style="list-style-type: none"><li>It's very helpful for people who have lost a something in their muscles, it will be very helpful for them to gain it.</li><li>It's fun, just like we watch 3-D movies or something like that.</li></ul>	<ul style="list-style-type: none"><li>The intensity I sensed, it's very minor, I would say I was fascinated with this because my finger was moving without me knowing it.</li></ul>	<ul style="list-style-type: none"><li>I think the advantage is just the very diverse range of applications.</li><li>Ensuring Safety</li></ul>

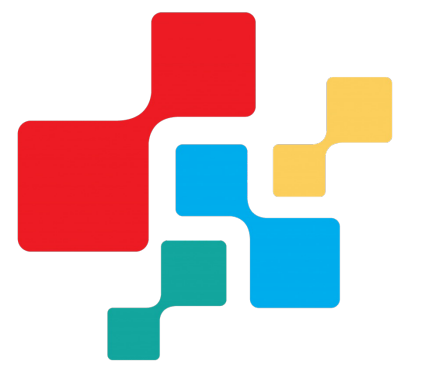




# Mixed Methods Research

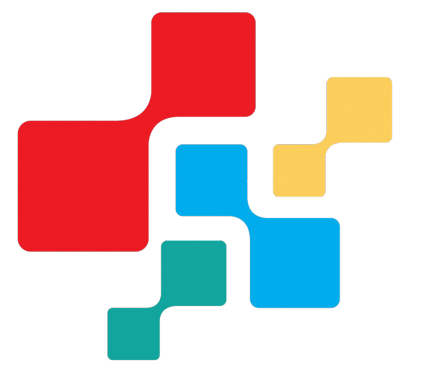


<https://www.youtube.com/watch?v=kxtCljBxjdM>



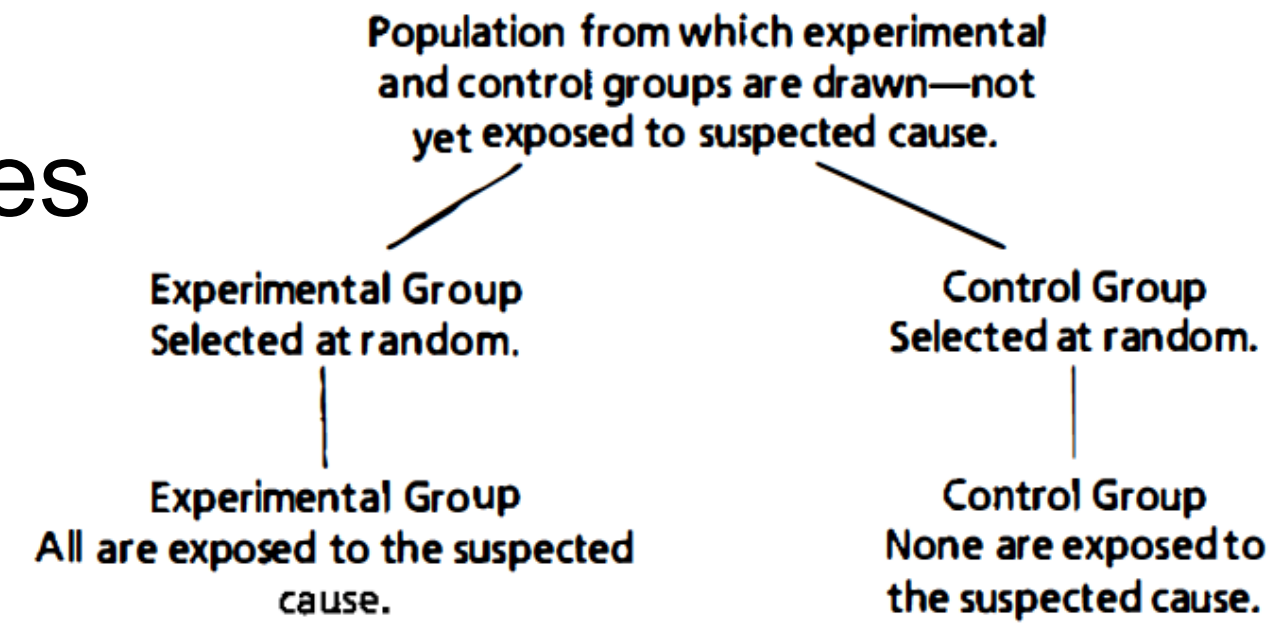
# Research Planning Steps

- ◉ Define research problem
- ◉ Choose method(s)
- ◉ Design study: variables, measures, sample
- ◉ Ethical considerations
- ◉ Pilot test if needed

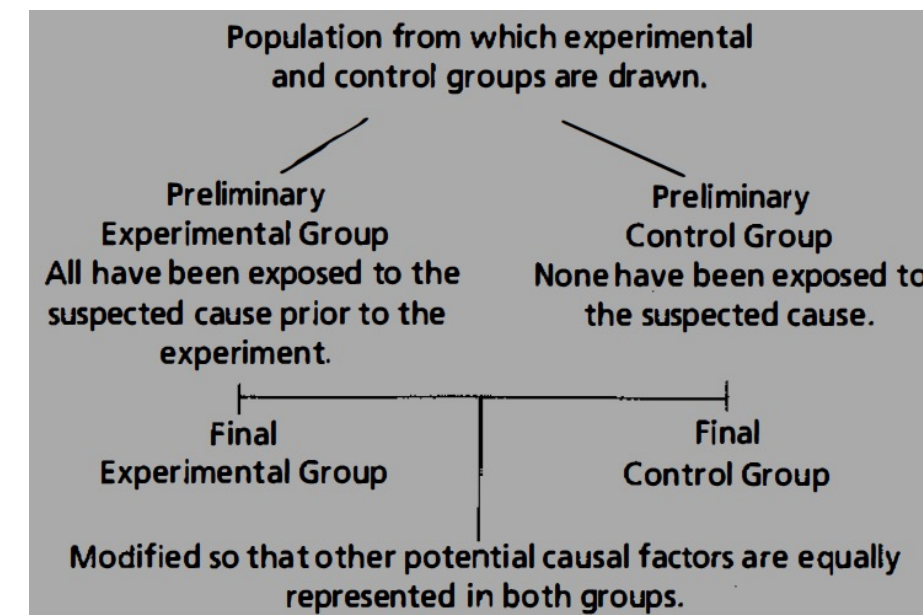


# Types of studies

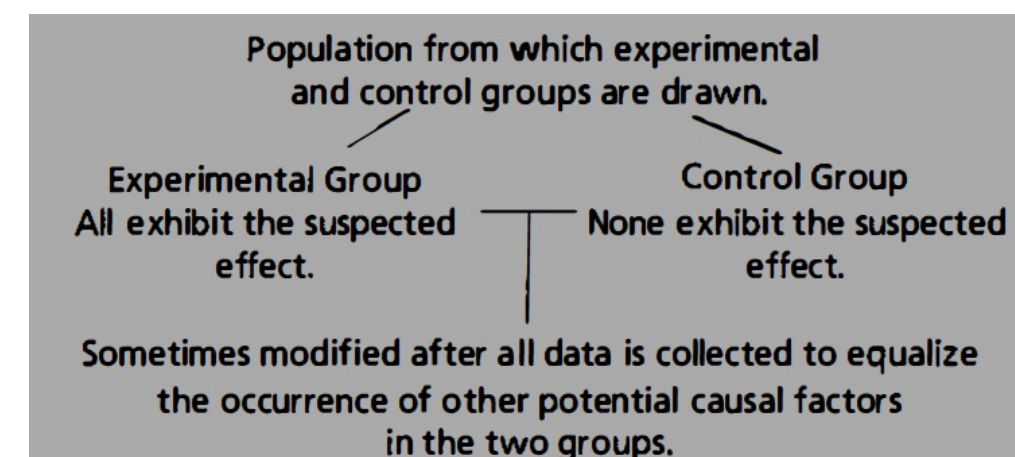
- Randomized Causal Studies

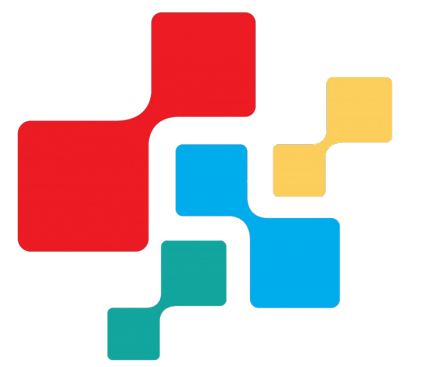


- Prospective causal studies



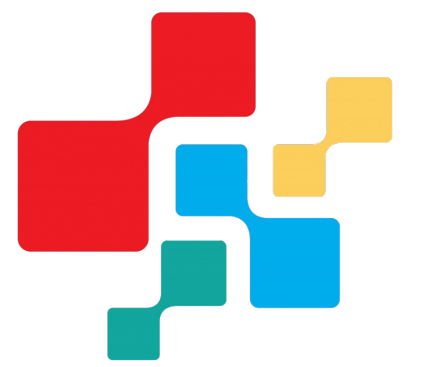
- Retrospective causal studies



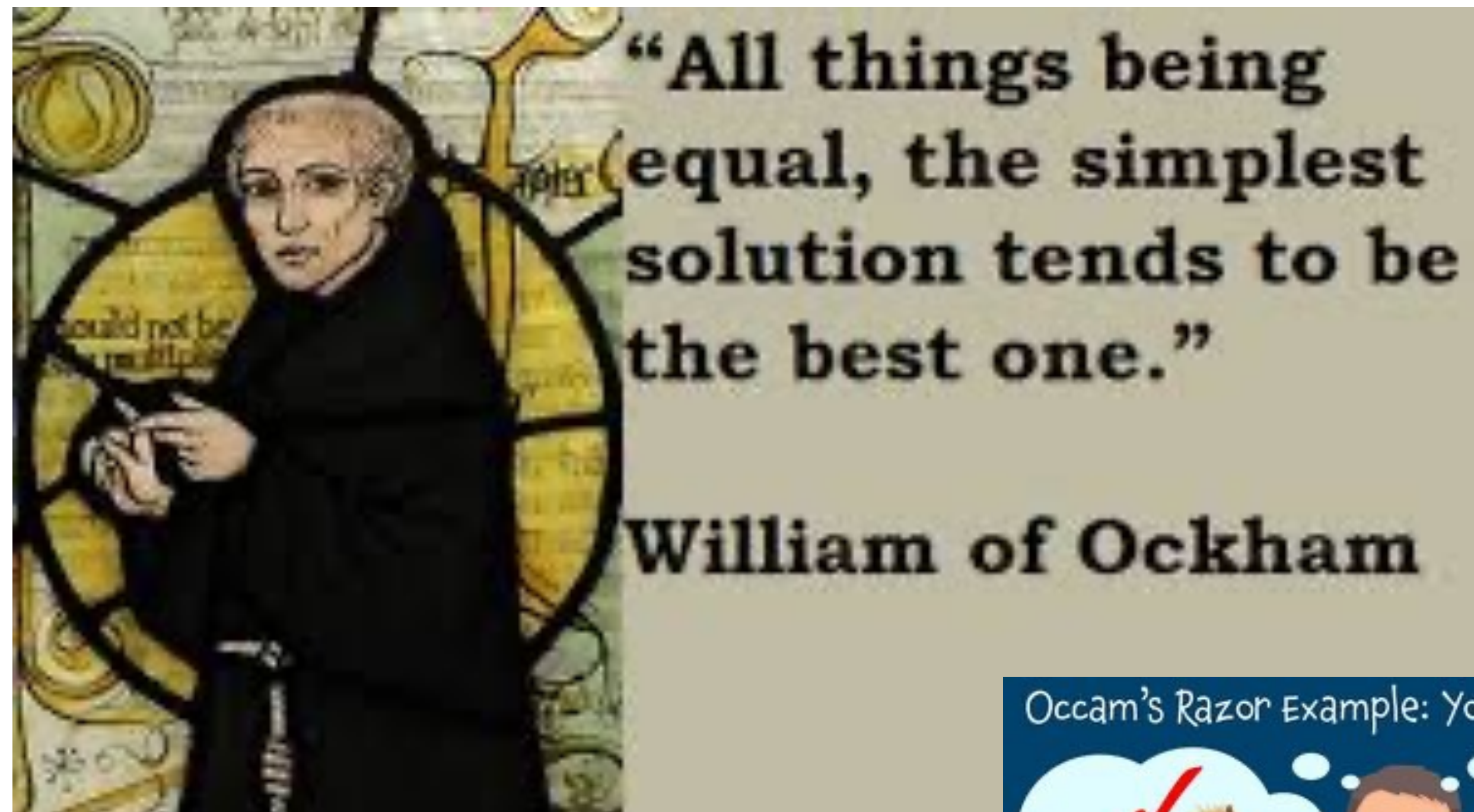


# Pitfalls and Best Practices

- ◉ Avoid p-hacking and cherry-picking
- ◉ Ensure reproducibility
- ◉ Acknowledge assumptions and limitations
- ◉ Be transparent in methods



# Rival explanations: Okham's razor



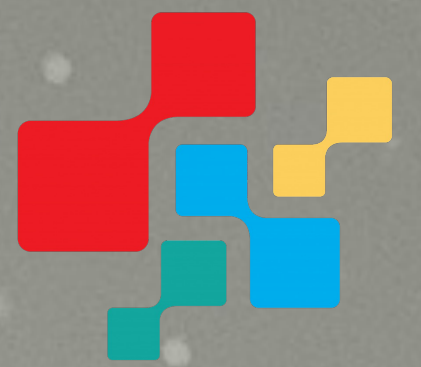
<https://www.youtube.com/watch?v=le53YZiRZy0>



<https://www.yourdictionary.com/articles/examples-occams-razor>



# Summary



- Research can be quantitative, qualitative, or mixed
- Qualitative helps to understand, quantitative to justify
- Research needs to be transparent and reproducible
- According to Okham the most simple explanation is favored

