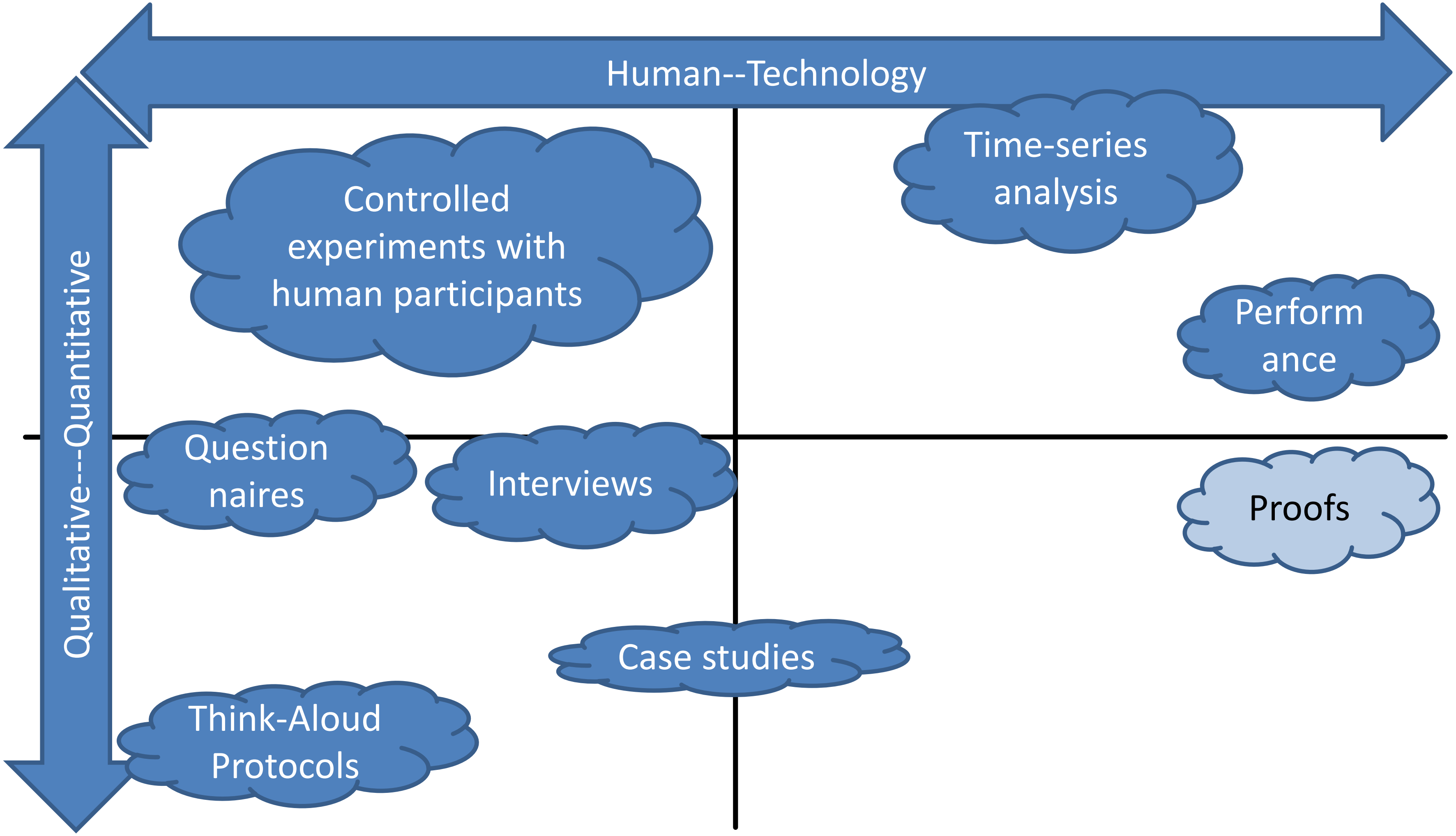
UNIVERSITÄT PASSAU

Fakultät für Informatik und Mathematik

Controlled Experiments

Overview


Human--Technology
Qualitative---Quantitative
Controlled experiments with human participants
Time-series analysis
Perform ance
Question naires
Interviews
Proofs
Case studies
Think-Aloud Protocols

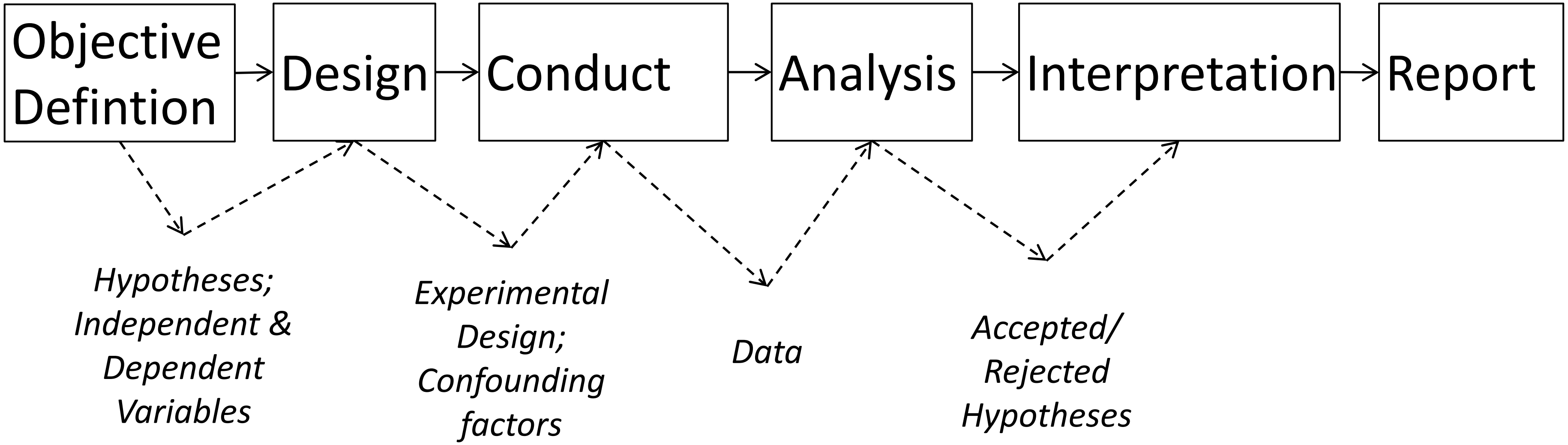
Learning Goals

- Design good research hypotheses
- Design an experiment with high internal validity and high external validity

Controlled Experiment: Definition

- Systematic study
- One or more factors are varied
- Everything else is held constant
- Result of systematic variation is observed

Experimental Phases


Objective Defintion
Design
Conduct
Analysis
Interpretation
Report
Hypotheses; Independent & Dependent Variables
Experimental Design; Confounding factors
Data
Accepted/ Rejected Hypotheses

Variables

Independent Variables

- Varied by experimenter on purpose and systematic
- Also called factor or predictor (-variable)
- Has alternatives, levels, or treatments

- Examples:
  - Programming language or paradigm
  - User interfaces
  - Interaction methods

Dependent Variable

- Result of an experiment
- Depends on variation of independent variable
- Is observed

- Examples:
  - Productivity of programmer
  - Bugs in a program
  - Operator error

Latent Variables

- Construct
- Not observable directly

- Examples
  - Program comprehension
  - Intelligence
  - Mental model of user

Operationalization

- Defining operations that allows you to measure variables
- Must not contradict common sense

- Example:
  - Program comprehension
    - Number of bugs in a program
    - Development time

Task

- Find operational definition for the following variables:
  - Usability of new UI
  - Maintainability of a program

Hypotheses

- Expectations of results
- Expecations need to be justified, e.g., in theory or practice
- Hypotheses need to be simple and clear
- Hypotheses need to be falsifiable
- Falsifiability (Homework assignment: Make yourself familiar with the term and explain its role for experimental design)

Hypotheses- Bad Examples

- Bad source-code comments are bad for program comprehension
- Good source-code comments are good for program comprehension

How can we do better?

- Comments that describe every statement of source code do not affect the time developers need to understand a source-code snippet
- Comments that contain wrong information about source code increase the time developers need to understand a source-code snippet
- Comments describing the purpose of source-code statements decrease the time developers need to understand a source-code snippet

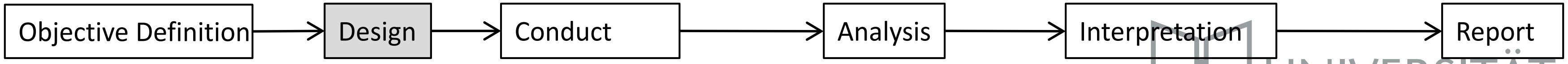
Why do we need Hypotheses?

- They guide us when designing an experiment
- Prohibit *Fishing for Results*
- Connects theory and empirical research
  - Derived from theory
  - Evaluated with empirical research

Task

- State a hypothesis on the following research questions:
  - Does Python increase productivty of developers?
  - Is Pyhton better than C++?
  - Is the new UI more productive?
- Keep in mind that the hypothesis needs to be evaluated, justified, and the variables operationalized

= Example for an exam question



Objective Definition → Design → Conduct → Analysis → Interpretation → Report

Design

Validity

- Do we measure what we want to measure?

Internal Validity

- Amount to which the value of the dependent variable can be explained my the systematic variation of the independent variable

External Validity

- Amount to which results are transferable to other circumstances (participants, material,…)
- Generalizability

Homework Assignment

- Research other kinds of validity

Threats to Validity

- Confounding factors:
  - Influence dependent variable in addition to indepedent variables
  - Learning effect
  - Hawthorne effect
  - Mono-method bias
  - Selection bias

Task

- Evaluating the effect of new UI: What confounding factors exist?
- How could the influence of these factors be controlled?

Confounding Factors

- There are numerous confounding factors
- Carefully identify and control their influence:
  - Randomization
  - Matching/parallelization/balancing
  - Define confounding factors as independent variable
  - Keep confounding factor constant
  - Analyze afterwards

Randomization

- Random numer generator
- Toss a coin
- Throw a dice
- …

- Issues:
  - Groups need to be sufficiently large
  - 5 per group seems to be too low, 10 seems to be sufficient

Matching/parallelization/balancing

Participant	Value
P5	65
P9	56
P3	42
P4	34
P10	24
P6	23
P7	21
P8	16
P2	12
P1	5

Group A	Group B
65	56
34	42
24	23
16	21
12	6

odd-even-even-odd/
ABBA

Matching/parallelization/balancing

- Drawback compared to randomization
  - Confounding factor needs to be measured
  - How to measure programming experience? How to measure intelligence?
- Advantage compared to randomization:
  - More detailed knowledge about parameter

Define confounding factors as independent variable

- Is varied systematically by experimenter
- Confounding factor is operationalized
- Experience with tool:
  - New UI/low experience
  - Old UI/much experience
  - New UI/low experience
  - Old UI/much experience

Doing the Math…

- 23 confounding factors, each with 2 levels

  = 8 388 608 possible combinations
- How many participants do I need to cover each combination
  - at least 10 participants per group
  - 83 886 080 (i.e., Germany)

Keep confounding factor constant

- Only one leve of confounding factor
- Programming experience:
  - Only undergraduate students
  - Only programming experts
- Intelligence
  - Only students with a certain grade

Analyze afterwards

- Measure factor during experiment
- Analyze influence of a variable after the experiment
- Issues
  - Could show that results are useless

Recommendation

- In your experiment, maximize internal validity
- In your experiment, maximize external validity

Relation between Internal and External Validity

- Both kinds of validity request different things:
  - Internal: control everything
  - Extern: general setting
- And now?
  - First maximize internal validity
  - Then increase external validity step by step

Quality Criteria of Empirical Studies

- Validity
- Reliability
- Objectivity

Quality Criteria of Empirical Studies

- Reliability:
  - Accuracy of measurement instrumenst

- Objectivity:
  - Execution of experiment must need depend on person of experimenter
  - The same experiment, conducted by a different experimenter, should produce the same result

Example

- Scale for measuring the weight:
  - Valid
  - Reliable depending on quality
  - Digital scale is more objective, as everyone sees the same number (analogous leaves more wiggle room)
- The same scale for measuring the height
  - Less valid
  - Reliable depending on quality

Experimental Designs

Designs

- Between vs. Within Subject

= With vs. without repeated measures

- One-factorial vs. multi-factorial

= One vs. several independent variables

- Univariate vs. Multivariate

= One vs. several dependent variables

Why Experimental Designs?

- Instruction to act
- Makes communication easier
- Decision for statistical analysis

How to Select a Design

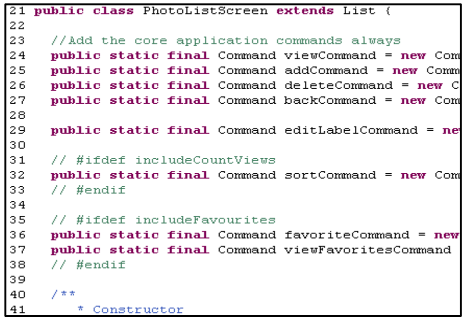
- Depends on:
  - Effect size
  - Sample size
  - -> The bigger both are, the less the influence of confounding factors manifest
  - -> When both are small, a suitable design is very important
- Unfortunately, you will very often have small samples and unknown effect sizes

One-Factorial

Between-Subjects

- Participants are devided into two groups
- As many group as there are levels of the independent variable
- Results are compared between groups

Gruppe	Stufen
A	Textuelle Annotationen
B	Hintergrundfarben



```
public class PhotoListScreen extends List {

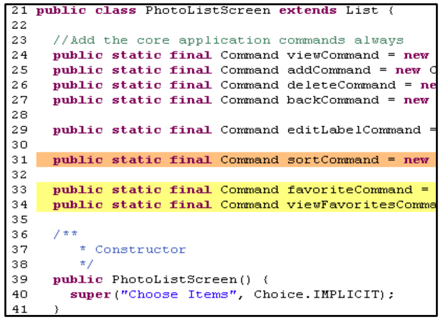
  //Add the core application commands always
  public static final Command viewCommand = new Com
  public static final Command addCommand = new Comm
  public static final Command deleteCommand = new C
  public static final Command backCommand = new Com

  public static final Command editLabelCommand = ne

  // #ifdef includeCountViews
  public static final Command sortCommand = new Com
  // #endif

  // #ifdef includeFavourites
  public static final Command favoriteCommand = new
  public static final Command viewFavoritesCommand
  // #endif

  /**
     * Constructor
```



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  public static final Command backCommand = new

  public static final Command editLabelCommand =

  public static final Command sortCommand = new

  public static final Command favoriteCommand =
  public static final Command viewFavoritesComma

  /**
     * Constructor
     */
  public PhotoListScreen() {
    super("Choose Items", Choice.IMPLICIT);
  }
```

Issues

- Variance between participants (i.e., inter individual differences) can be large
- -> 10x (What does 10x Mean? Measuring Variations in Programmer Productivity. Steve McConnell.)
- Sufficient number of participants
- Balancing between groups

Within-Subjects

- Inter individual differences need to be controlled for
- Each participant is exposed to all levels of an independent variable

One Group	Session 1	Session 2
	Background colors	Textual Annotations

Issues

- Learning effects
  - Especially with creative tasks
  - You need different, but similar tasks at the same time
- Ordering effects
- Intra individual differences
  - Fatigue
  - Motivation
- Mortality

Crossover

- Each participant is exposed to all levels
- Comparison between and within groups is possible

Group	Session 1	Session 2
A	Background colors	Textual annotations
B	Textual annotations	Background colors

Issues

- Intra individual differences
- Inter individuelle differences
- Mortality

Benefits

- Check for learning effects:
  - Difference between both sessions for both levels
- Check for ordering effects:
  - Difference between both sessions for one level

Gruppe	Session 1	Session 2
A	Background colors	Textual annotations
B	Textual annotations	Background colors

Comparison

Property	Between-Subjects	Within-Subjects	Cross-Over
Sample size	2	1	2
Group balancing	2	1	2
Learning effects	2	3	1
Ordering effects	2	3	1
Mortality	1	2	2
Motivation, fatigue	1	2	2
Experiment duration	1	2	2
Internal validity	2	2	1
External validity	2	2	1

Multi Factorial Designs

Latin Square

Group	Task 1	Task 2
A	Background colors	Textual annotations
B	Textual annotations	Background colors

- Special case of cross over
- But different task in sessions -> Task is second factor

Two-factorial, Between-subjects

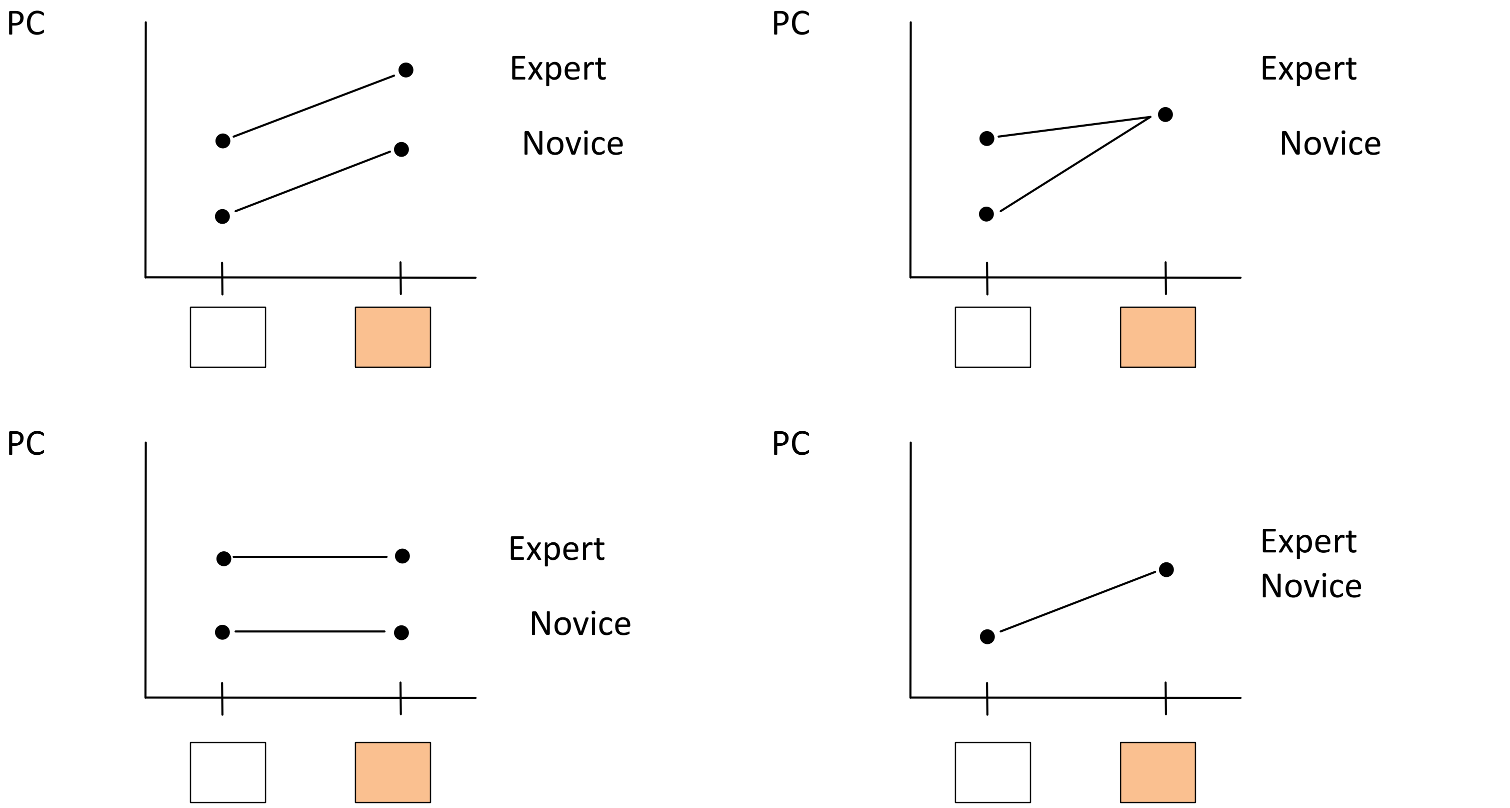
- Programming experience, Intelligence

Variables	Groups
Background color/ novice	Group A
Background color/ expert	Group B
Textual/ novice	Group C
Textual/ Expert	Group D

Two-factorial, Within-Subjects

Group	Session 1	Session 2	Session 3	Session 4
Background color/ novice	Group A	Group D	Group C	Group B
Background color/ expert	Group B	Group A	Group D	Group C
Textual/ novice	Group C	Group B	Group A	Group D
Textual/ Expert	Group D	Group C	Group B	Group A

Main- and Interaction Effects



Multi-factorial Designs

- In case the shown designs are not sufficient
- 4-factorial design (2x2x3x2)
- Higher-order interaction

		C_1		C_2		C_3	
		B_1	B_2	B_1	B_2	B_1	B_2
A_1	D_1						
	D_2						
A_2	D_1						
	D_2						

Selecting a Design

- Prefer a simple as possible design
- Carefully consider benefits and disadvantages
- Consider resource constraints

Homework assignments

- Why do we need hypotheses?
- What does falsifiability mean?
- Research other kinds of validity
- Design an experiment for a self-selected research question
  - Define hypotheses
  - Operationalize variables
  - Identify the most important confounding parameters (at least 5) and select suitable control techniques
  - (You do not need to think about statistical tests yet)

Conduct

What Can Go Wrong?

- Everything!
- Pilot studies:
  - Test material and tools
  - Check that data is actually stored
  - Check instructions for participants
  - …
- **Exactly** tell participants what they need to do
- Observe that participants do **exactly** what you told them they should do
- Do a warm-up task, so that participants can familiarze with everything

Ethics

- Effort for participants need to be in line with insights that you gain
  - Evaluating teaching methods
  - Evaluating medicine
- Ensure anonymity of participants
- Be nice to your participants, they voluntarily invest their time

Learning Goals

- Design good research hypotheses
- Design an experiment with high internal validity and high external validity

Task

- Following statements:
  - Program in Java can be easier debugged
  - Learning to program is the most easy with Haskell
  - Novice programmers should start with object orientation
  - …
- Define:
  - Hyptoheses
  - Dependent and independent variables and operationilzation
  - Confounding factors and how to control them
  - Experimental design

Literature

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