Empirical Software Engineering
Introduction & Basic Concepts

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Motivation

- A major goal in software engineering is the delivery of high-quality software solutions.
- The construction of software products requires professional approaches, e.g., software processes (e.g., Life-Cycle Model, V-Modell XT, Scrum).
- Methods support engineers in constructing and evaluating software products.
  - Constructive approaches, e.g., Model-Driven Development, Test-Driven Development, and pair programming to create new software products.
  - Analytical approaches, e.g., inspection and testing to assess product and process quality.
- Increasing product quality (e.g. less defects), project and process performance (faster delivery of products) requires the application of improved methods and tools.

Questions

→ How can we evaluate and assess improved methods and processes?

→ How can we measure process / product attributes in general?

→ How can we conduct an empirical study?

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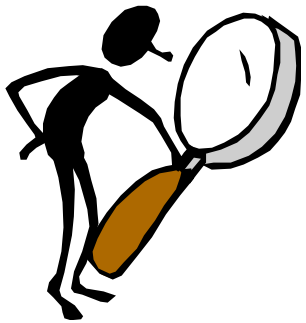
- Need for empirical studies in the context of software engineering.
- Basic Concepts: Measurement, Collection, Analysis
- Goal Question Metric
- Empirical Strategies: survey, case study, controlled experiment
- Process of an empirical study

Reasons to Conduct Empirical Studies

- New software development technologies come up frequently, e.g. tools, methods
  - Question: Why should we invest in those technologies?
- In other disciplines, technology evaluation is a pre-requisite, …
  … but not in software engineering…
  - Often intuition: “I believe that my method is better than XYZ”?
- Empirical studies in SE are necessary:
  - To prove theories and ‘general wisdom’.
    Example: OO is better
  - To find relationships.
    Example: Relationship between Maintainability and its metrics (e.g. LoC)
  - To choose amongst models/techniques/tools.
    Example: development approaches, inspection reading techniques
  - To judge on the accuracy of models.
    Example: cost models



Need of Empirical Studies

Why should we conduct empirical studies?

- Product evaluation, e.g., prototyping.
- Process evaluation
  - Prototypes are not possible (simulation based on models).
  - A process is just a description until it is used by people.
- Important for research: experimentation is mandatory in other disciplines (e.g., medicine, physics, etc.)
- Experimentation provides a systematic, disciplined, quantifiable and controlled way of evaluating human-based activities.

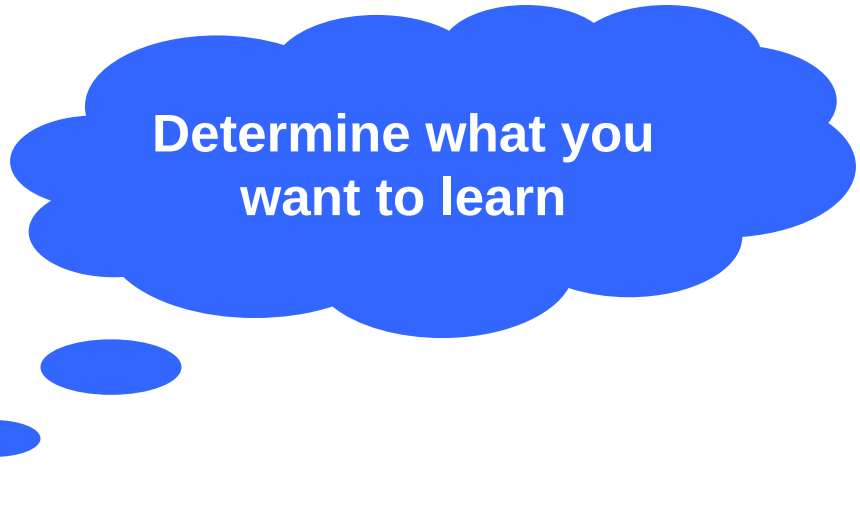
→ You will learn how to select, plan, conduct and analyse an empirical study.

Goals and Benefits

The purpose of a study is

- to explore ...
  - to find out what's happening
  - to seek for new insights
  - to ask questions and to find answers
  - Measurement: usually qualitative
- to describe ...
  - portray accurate profile of situations, events, projects, technologies
  - Measurement: quantitative/qualitative
- to explain ...
  - seek explanation of a situation/problem, usual in the form of causal relationships
  - Measurement: quantitative/qualitative

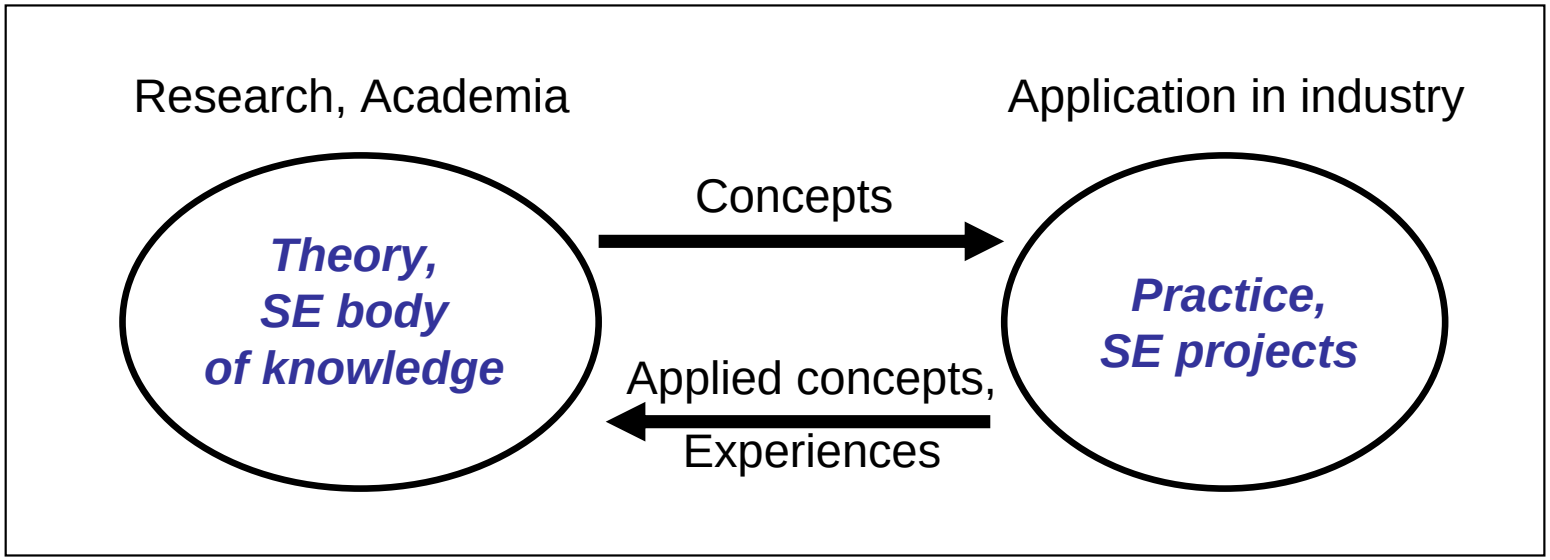
- … relationships, differences, changes



Empirical Studies in SE

Empirical Studies is research to improve Software Engineering Practice.

- Apply theoretical concepts in SE practice.
- Add experiences on their appliance to the SE ‘body of knowledge’
- Improve processes, methods and tools (SPPI approach).
- Verify theories and models.

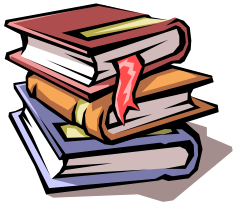


Objects of Empirical Research

Organization(s)

Software processes
e.g. testing process

Empirical Research



Product(s)
e.g. documents, software

Project(s)

Resources
people and tools to conduct process

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Some Basic Concepts

- Measurement
  - is the process of capturing data which are connected to real-world attributes to describe them.
  - Why is measurement important?
- Data Collection
  - Collection of qualitative / quantitative data according to research questions.
- Data Analysis
  - Analyzing the results according to the research questions; statistical tests.

Measurement

- **Quotes**:
  - “You can’t manage what you can’t measure”, Tom DeMarco
  - “What is not measurable make measurable”, Galileo Galilei

- **Objectives**:
  - One objective of science is to find ways to measure attributes of entities we are interested in.
  - Measurement makes concepts more visible and thus more understandable and controllable.

- **Definition**
  - Measurement is the process by which numbers or symbols are mapped to attributes of entities in the real world in such a way as to describe them according to clearly defined rules.

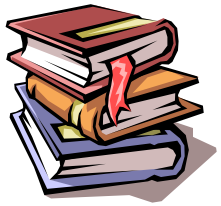
Measurement (Examples)

Process

effort → person days spent from start to end → 10 weeks

- Examples: Development process (V-Modell XT), Testing Process, Inspection, ..

Product



size → No. Lines of Code → 700 LOCs

- Examples: Design Specification (No of pages), Test Suite (number of test cases), Module (LoCs)

Resources

experience → >10 projects → high

- Examples: Project management experience, Testing experience, Design / Architecture experience.

Selected Types of Measures

- Direct vs. Indirect Measures:
  - Direct: obtaining values direct from the study object (e.g., duration, effort)
  - Indirect: calculated values based on various attributes (e.g., efficiency of defect detection = number of defects per time interval)

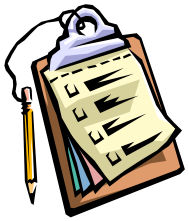
- Objective vs. Subjective Measures:
  - Objective: no judgment in measurement value (e.g., LoC, delivery date)
  - Subjective: reflect judgment of the measurer, depending on the viewpoint
    (e.g., subject defect estimation, questionnaires)

- Quantitative vs. Qualitative data:
  - Quantitative: data expressed as numbers (e.g., data obtained through measurement, statistics)
  - Qualitative: data expressed as word and pictures (e.g., interviews, interpretation)

Data Collection

- Measurement
  focuses on products, processes (typically quantitative data collection)

- Interviews
  based on information obtained from individuals persons or groups (typically qualitative data)



- Questionnaires
  set of questions to obtain information from individuals, e.g., experience, feedback; (typically used in surveys)

- Observation
  selection, recording, and encoding of a set of natural behaviours or other naturally occurring phenomena (typically used in case studies)

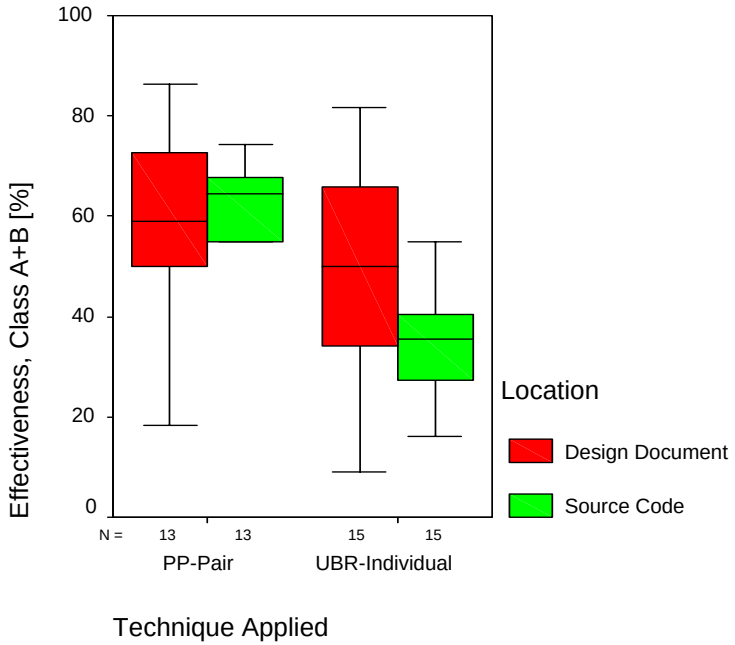
Data Analysis

Purposes of quantitative data analysis

- Describing a population (descriptive statistics)
- Exploring differences between groups (Hypothesis Testing)

Examples:

- Minimum, Mean, Maximum, Standard Deviation.
- Visualization, Statistical Tests to test Hypothesis.



Statistical Tests

	Location	PP-Pair	UBR-Individuals	P-value
Mean	DD+SC	56.3	40.3	0.013 (S)
	DD	56.3	47.3	0.212 (-)
	SC	56.3	35.3	0.004 (S)
Std.Dev	DD+SC	20.6	13.6	-
	DD	26.7	20.6	-
	SC	17.9	11.4	-

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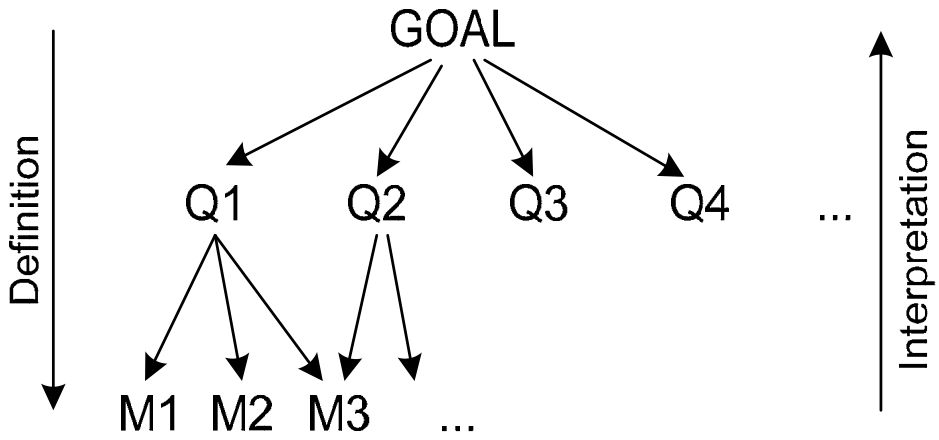
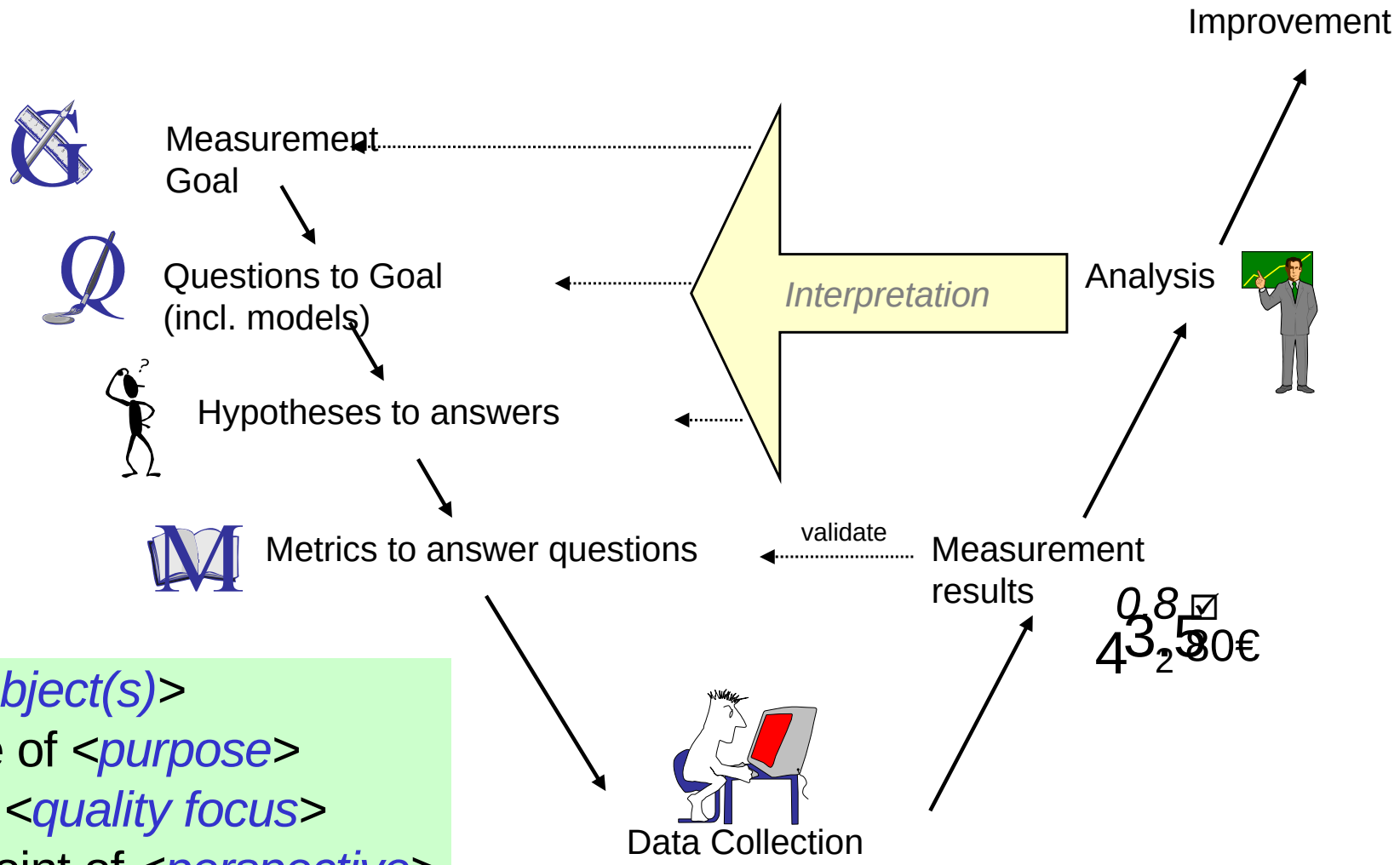
Goal Question Metrics (GQM)

- A framework for systematic measurement, data collection and analysis.
- The main goal of GQM is to provide a framework for the measurement of software quality [Basili et al, 2000]

- GQM consists of three major levels:
  - Conceptual level (GOAL)
    Objects of measurement are products, processes, and resources
  - Operative Level (QUESTION)
    characterization of questions according to the goals.
  - Quantitative Level (METRIC)
    Measures to answer defined questions.



GQM Methodology

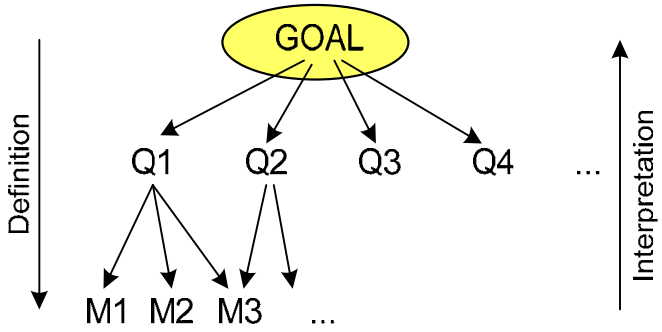


Analyze the <*object(s)*>
for the purpose of <*purpose*>
with respect to <*quality focus*>
from the viewpoint of <*perspective*>
in the context of <*context*>

GQM-Goal Template

Example: GQM Goals

- The management wants to optimize software project development costs.
- Required information: Project effort / duration within individual development phases for selected projects.
- How can we achieve this information?



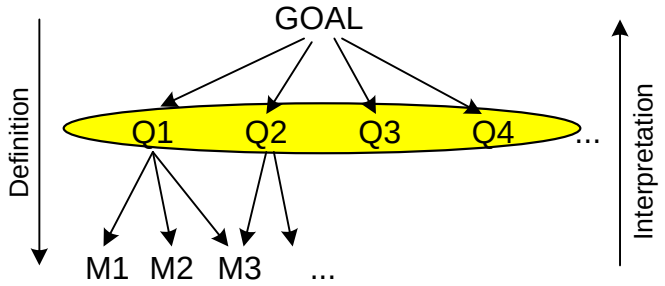
Step 1: Derive goal (based on the GQM template):

→ Characterization of software development costs in a certain project.

- Analyze the software development process (object)
- for the purpose of characterization (purpose)
- with respect to effort (quality focus)
- from the viewpoint of the management (perspective)
- in the context project A (context)

Example: Required information to achieve the goal

Step 2: Derive appropriate questions



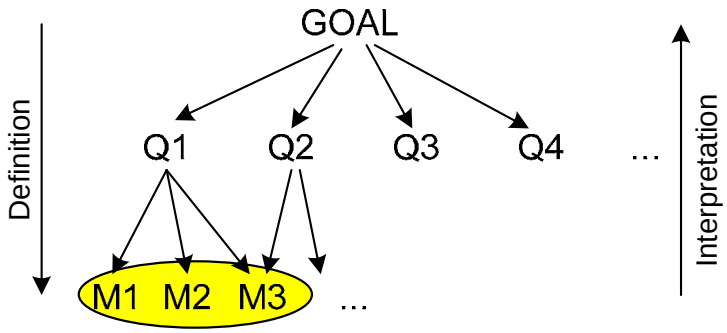
- What information is required to achieve the measurement goal?

- Some possible questions:
  - What is the distribution of effort among development phases/activities?
  - Define the typical effort per module / component (comparability of the complexity of individual modules / components)
  - Define the effort spent on rework (in case of defects)
  - How many hours are spent on documentation?
  - …

- A set of questions operationally define the goal.
- A set of metrics provide answers to every question.

Example: Metrics to describe process behavior

- Metrics to measure product / project attributes regarding the goal of the investigation.



- Examples:
- What is the distribution of effort among development phases/activities?
  - Person months for every phase (e.g., 5 person months for requirements elicitation; 4 person months for design …)
  - Duration in months, i.e., 1 months for requirements involving 5 persons.

- Define the typical effort per module / component (comparability of the complexity of individual modules / components)
  - Depending on the architecture and design
  - Consider different levels of systems complexity.
- Number of defects found during review cycles (rework / QA effort)
  - Decision to include additional analytical quality assurance steps.

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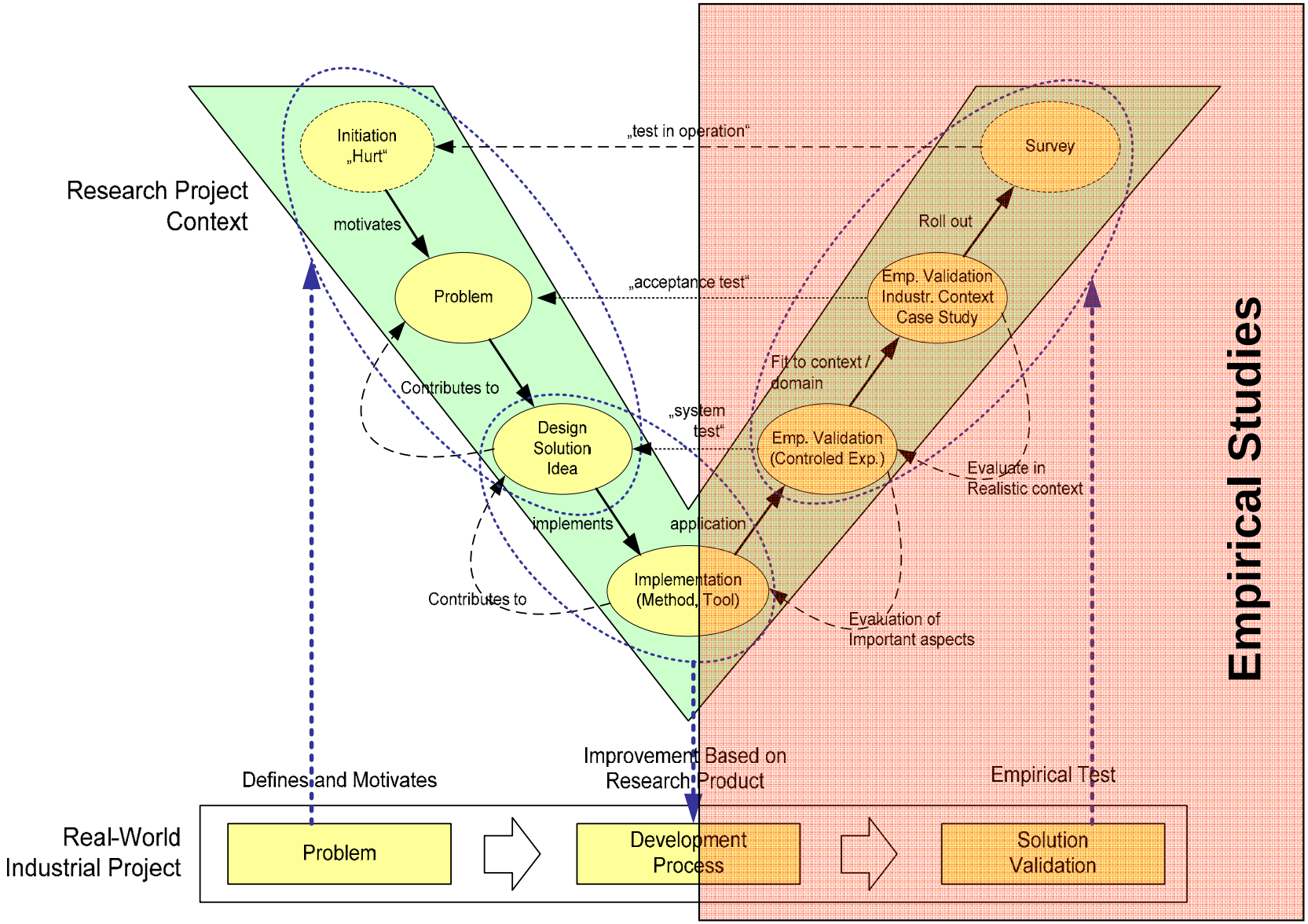
Introduction

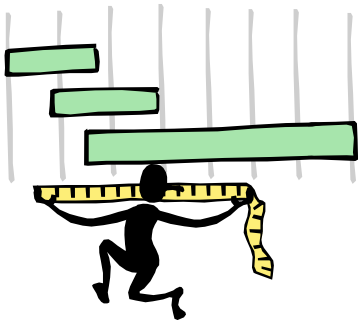
- Empirical studies provide a systematic, disciplined, quantifiable and controlled way of evaluating human-based activities.
- Empirical studies are important for scientific work to get knowledge of products, processes and resources (V-model).
- Empirical methods are important techniques for software quality improvement.
- Different study strategies aim at focusing on individual steps of product / process progress (e.g., laboratory evaluation and simulation, organization case studies, cross-company surveys etc.)

- You will learn
  - V-Model of empirical software engineering.
  - Different strategies of empirical research (survey, case study, controlled experiment)

Empirical Studies in the Context of the V-Model



Different Empirical Strategies



Controlled Experiments

- Measuring the effects of one or more variable(s) on other variable(s)
- Detailed investigation in controlled conditions (relevant variables can be manipulated directly, precisely and systematically)

Case Studies

- Development of detailed, intensive knowledge about a single case or of a small number of related cases
- Detailed investigation in typical conditions

Surveys

- Collection of information in standardized form from groups of people or projects.
- Usually performed retrospectively.
- The use of a technique/tool has already taken place, relationships and outcomes should be documented.

Empirical Strategies

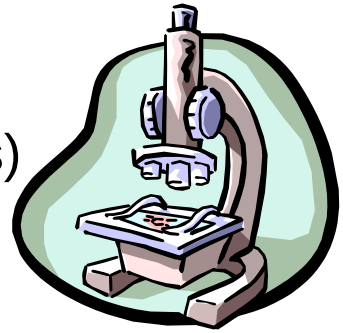
- Controlled Experiment:
  - laboratory environment.
  - an operation is carried out under controlled conditions.
  - manipulate one or more variables and keep all other variables at fixed levels.
- Case Study:
  - Monitoring projects or activities.
  - data collection for a specific purpose.
  - observational study.
- Survey:
  - investigation performed in retrospect.
  - interviews and questionnaires.

Strategy	**Quantitative** (data expressed as numbers)	**Qualitative** (data expressed as words or pictures)	**Study Effort** (always depends on context and research topic)
Experiment	X		(very) high
Case Study	X	X	Medium
Survey	X	X	Low/Medium

Controlled Experiment: Fact Sheet

Purpose:

- Measuring the effects of one or more variable(s) on other variable(s)
- Detailed investigation in controlled conditions (relevant variables can be manipulated directly, precisely and systematically)

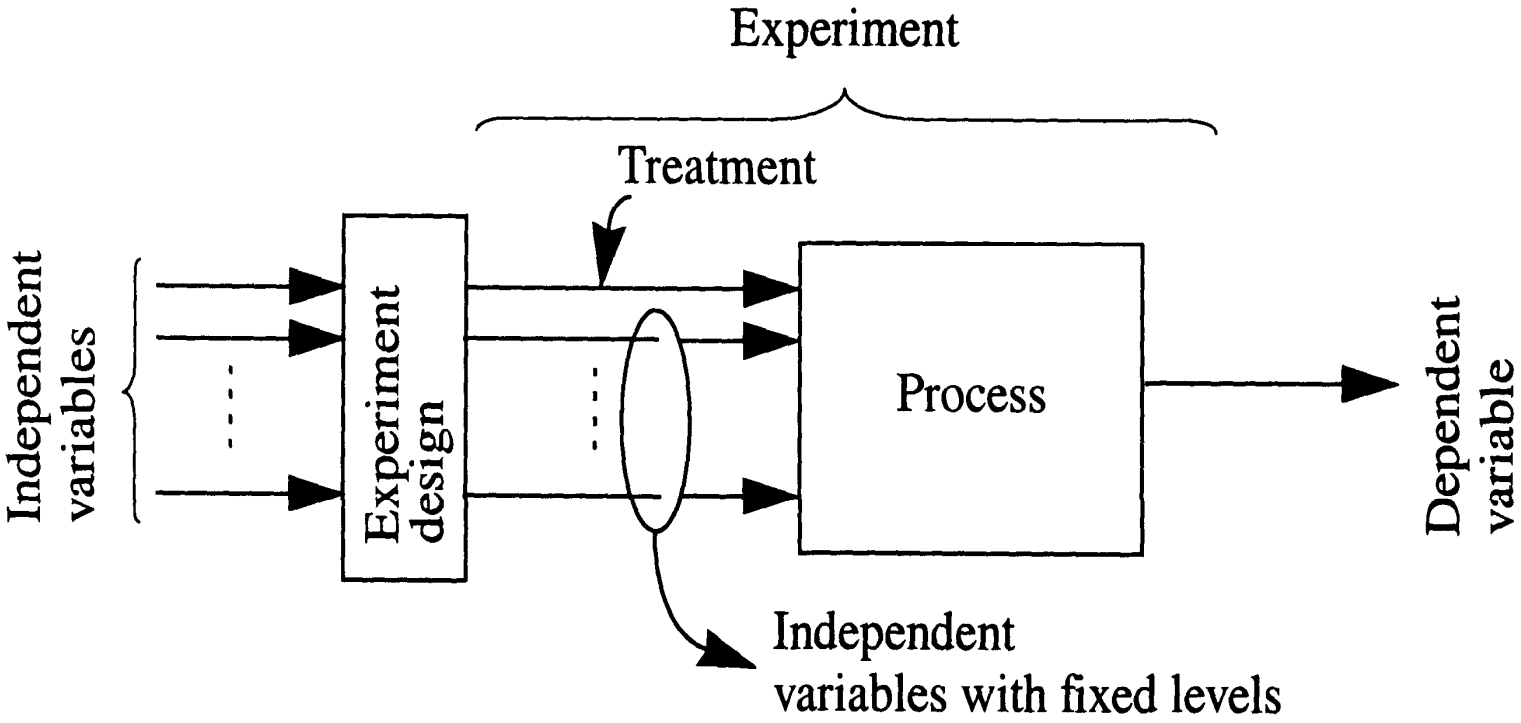


When select an experiment?

- When appropriate: control on who is using which technology, when, where and under which conditions.
- Level of control: high
- Data collection: process and product measurement, questionnaires
- Data analysis: statistics, compare of groups, treatments, etc.

- Pro's: help establishing causal relationships, confirm theories.
- Con's: representative? Challenging to plan in a real-world environment. Application in industrial context requires compromises.

An Experiment

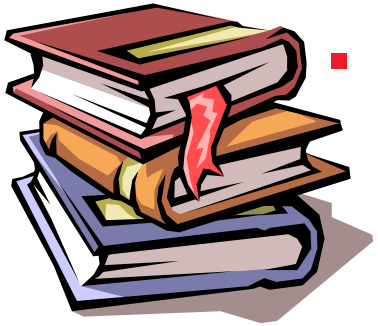


Wohlin et al., Experimentation in Software Engineering, Kluwer Academic Publishers, 2000.

Experimentation Vocabulary

- Dependent Variable: studied to see the effect of changes in the independent variables (e.g. productivity of development team)
- Independent Variable: all variables that are manipulated and controlled (e.g. new development method, experience of developers)
  - Factor: set of investigated independent variables.
  - Treatment: one particular value of a factor (e.g. new and old development method)
- Objects (e.g. documents) and subjects (i.e. participants)

Case Study: Definition



- Empirical study to objectively investigate a new technology in a somewhat realistic setting.
- Method for research evaluation by monitoring a project and collecting data over time. Data collection is derived from a specific goal for the project.
  A certain attribute (e.g., reliability, cost) is monitored and data is collected to measure that attribute. [Zelkowitz et al., 1998].
- Trial use of a technology on a full-scale project, with the objective of comparing the effect of the new technology with that of other technologies or current practice.

Case Study: Fact Sheet

Purpose:

- Development of detailed, intensive knowledge about a single case or of a small number of related cases.
- Detailed investigation in typical conditions.

When select a Case Study?

- When appropriate: change (new technology) is wide-ranging throughout the development process, want to assess a change in a typical situation
- Level of control: medium
- Data collection: product and process measurement, questionnaires, interviews
- Data analysis: compare case study results to a baseline (sister project, company baseline)

- Pro's: applicable to real world projects, help answering why and how questions, provide qualitative insight
- Con's: difficult to implement a case study design, analysis of results is subjective

Survey: Fact Sheet

Purpose:

- A retrospective study of a situation to try to document relationships outcomes.

When select a survey?

- When appropriate: for early exploratory analysis. Technology change implemented across a large number of projects, description of results, influence factors.
- Level of control: low
- Data collection: questionnaires, interviews
- Data analysis: comparing different populations among respondents, association and trend analysis, consistency of scores.

- Pro's: generalization of results is usually easier (than case study), applicable in practice.
- Con's: little control of variables, questionnaire design is difficult (validity, reliability), execution is often time consuming (interviews).

Survey Types in Software Engineering

State-of-the-art Surveys

- Ask people on state-of-the-practice, best practices.
  - Inside an organization: people, departments, business units
  - Over organizations: people with a specific function (e.g. QA, engineer), people in specific departments.

Literature Surveys

- Analyze existing literature (papers, books, notes) to determine the state-of-the-art, best practices on a topic.

Trend Surveys

- Evaluate demand of particular products or services and predict their future.
  - Conducted by institutes like Ovum, Gartner & IDC.
  - Also by asking people in organisation.

Selecting an Empirical Strategy

How to select the appropriate strategy for a study:

- Purpose of study
  - Exploratory, descriptive or confirmatory
  - Questions concerning what, how, how many, where, for whom
- Degree of control
  - Possibility to ‘arrange’ the real world
  - Required versus possible degree of control
- Cost
  - The relative costs for doing a study;
    e.g. costs for doing experiments are considered as being high
- Risk
  - Probability that study might fail and its consequence

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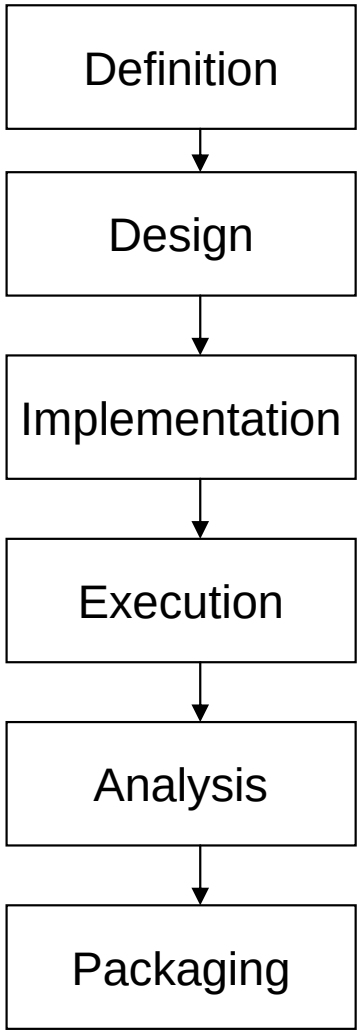
„High-Level“ Experiment Process

An overview on the high level process

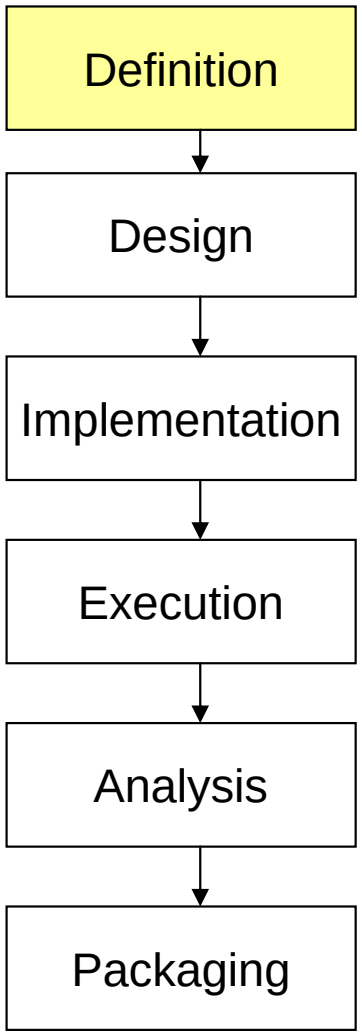


- Definition: Determine study goal(s) and research hypothesis(es). Select type of empirical study to be employed.
- Design: Operationalize study goal(s) and hypotheses. Make study plan: what needs to be done by whom and when.
- Implementation: Prepare material required to conduct the study.
- Execution: Run study according to plan and collect required data.
- Analysis: Analyze collected data to answer operationalized study goal and hypotheses
- Packaging: Report your study so that external parties are able to understand results and context of the study.

Research Proposal: Content

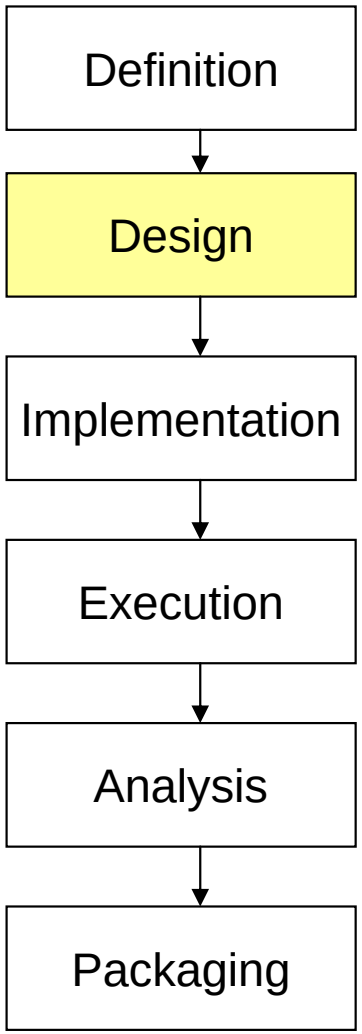
1. **Introduction and motivation**
   - why is the research relevant.
   - description of issues or points.
2. **Relevant prior work**
   - what is the work based on.
   - what are the other relevant research results.
   - what is the "research gap" that this research contributes to.
   - it is sufficient to refer to main relevant work.
3. **Research Objectives, questions and hypotheses**
   - explicit articulation of the research objectives (higher level goals for the research)
   - explicit definition of the research hypotheses and questions (more specific statement)
4. **Empirical study design and arrangements**
   - overall design of the study.
   - description of study arrangements.
   - description data collection procedures and protocols.
5. **Definition of metrics**
   - definition of metrics used in the study, include a list and definition of most important metrics.
6. **Data analysis methods**
   - description of the methods and techniques used in data analysis.
7. **Validity threats and control**
   - description of potential threats and how they will be mitigated
   - how generalizeable the results are?

Experiment Process: Definition



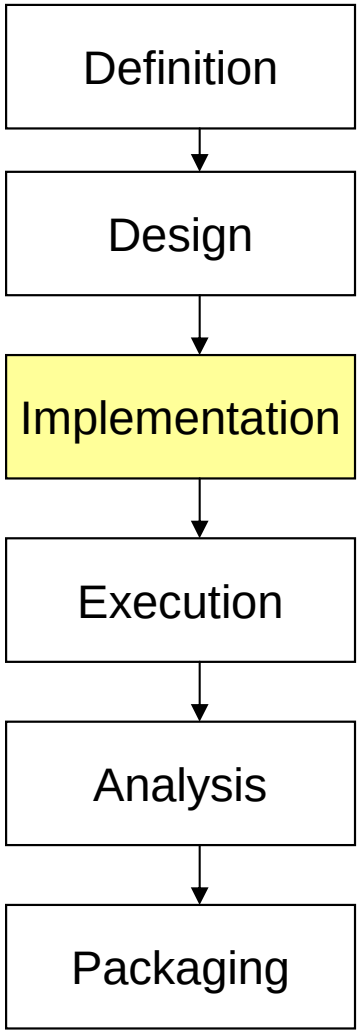
- Determine study goal(s) and research hypothesis(es). Select type of empirical study to be employed.
- Define Research Objectives:
  - explicit articulation of the research objectives (higher level goals for the research)
  - Example: the new model will improve software development productivity.
- Define Hypotheses:
  - explicit definition of the research hypotheses and questions (more specific)
  - Example: Method 1 performs better than method 2, because …

Experiment Process: Design



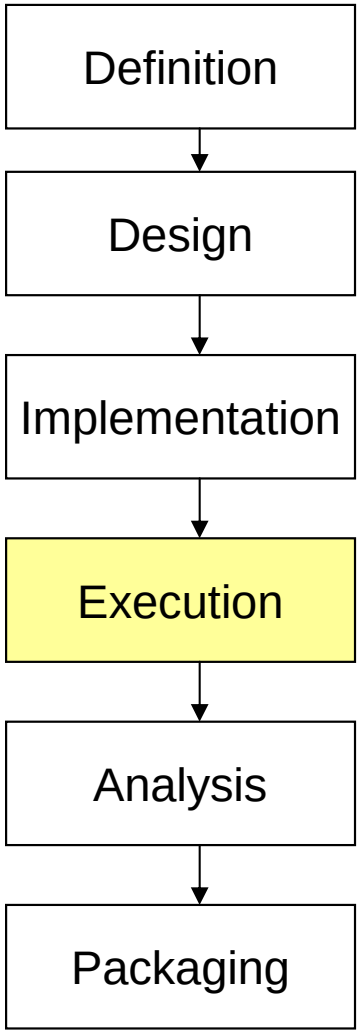
- Operationalize study goal(s) and hypothesis(es).
  Make study plan: what needs to be done by whom and when.
- Determine what needs to be observed / measured;
  quantitative and qualitative data.
- Maximize validity of results;
  identify what effects might influence my findings.
- Maximize reliability of the study (to enable replication)
  → documentation of procedures, context, measurements.

Experiment Process: Implementation



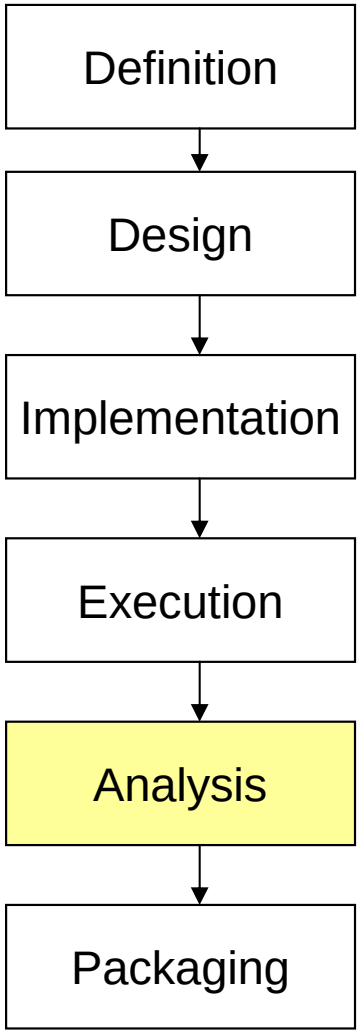
- Prepare material required to conduct the study.
- Use intensive reviews to check the experiment material for correctness.
- Apply Pilot-Tests to verify / improve the experiment material.
  - Are instructions clear, understandable, consistent?
  - Are tasks too simple or too difficult?
  - Can all data be collected as intended?
  - Is the schedule appropriately planned?
  - Note: participants in pilot-tests should be representative for subjects.
- Example:
  - We conducted a pilot study (including a smaller number of participants) with similar material to verify and improve the experiment package.

Experiment Process: Execution



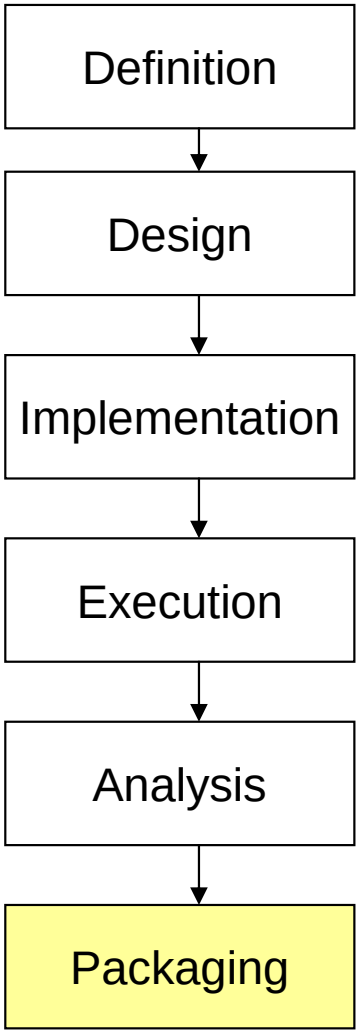
- Run study according to plan and collect required data.
- Example:
  - Paper-based data collection (during the experiment)
  - Separated data submission session using a web-tool.

Experiment Process: Analysis



- Analyze collected data to answer operationalized study goal and hypotheses.
- Basic Steps:
  - Data collection
  - Check data for consistency and credibility
  - Create descriptive statistics and visualize data
  - Perform statistical analysis / comparison
  - Interpret results.
- Data validation ensures the correctness and completeness of collected data. Consider …
  - exceptionally high/low values, Null Values
  - Missing Values, Missing Records
  - Inconsistent values

Experiment Process: Packaging & Publication



- Report your study so that external parties are able to understand results and context of the study.
- Report your study to be replicated by others.

Summary

- Experimentation provides a systematic, disciplined, quantifiable and controlled way of evaluating human-based activities.
- The purpose of a study is to explore, to describe, and to explain relationships, differences, changes of products, processes, and resources.
- Measurement provides quantitative and qualitative data of the study object.
- Data collection approaches are basic elements of empirical studies (e.g. measurement, interviews, questionnaires, observation).
- Data analysis describes data of the study, relationships between different entities, etc. Statistical tests are used to falsify hypothesis.
- Goal question metric (GQM) approach is a framework for the measurement of software quality.
- Main study strategies are controlled experiments, case studies, and surveys.
- A study consists of a defined sequence of steps (from definition of the initial study to packaging and reporting of study results).

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Thank you for your attention

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