Empirical Software Engineering
Introduction & Basic Concepts

Dietmar Winkler
Vienna University of Technology
Institute of Software Technology and Interactive Systems
dietmar.winkler@qse.ifs.tuwien.ac.at
http://qse.ifs.tuwien.ac.at
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

Determine what you want to learn
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.

Research, Academia

Theory, SE body of knowledge

Concepts

Applied concepts, Experiences

Application in industry

Practice, SE projects
Objects of Empirical Research

- **Organization(s)**
- **Project(s)**
- **Resources**
- **Software processes**
  - e.g. testing process
- **Product(s)**
  - e.g. documents, software

Empirical Research

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

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


time

10 weeks

person days spent from start to end

size

700 LOCs

Product

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

Resources

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

experience

>10 projects

high
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.
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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.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Quantitative (data expressed as numbers)</th>
<th>Qualitative (data expressed as words or pictures)</th>
<th>Study Effort (always depends on context and research topic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>X</td>
<td></td>
<td>(very) high</td>
</tr>
<tr>
<td>Case Study</td>
<td>X</td>
<td>X</td>
<td>Medium</td>
</tr>
<tr>
<td>Survey</td>
<td>X</td>
<td>X</td>
<td>Low/Medium</td>
</tr>
</tbody>
</table>
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

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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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?
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 …
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.
- 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.
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**

- **Definition**
- **Design**
- **Implementation**
- **Execution**
- **Analysis**
- **Packaging**

- 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
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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.

Experiment Process: Packaging & Publication

- Definition
- Design
- Implementation
- Execution
- Analysis
- Packaging

TU Vienna
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).
References

- ISEE Tutorials on Empirical Software Engineering.
Thank you for your attention

Contact:
Dipl.-Ing. Dietmar Winkler
Vienna University of Technology
Institute of Software Technology and Interactive Systems
Favoritenstr. 9-11/188, A-1040 Vienna, Austria

dietmar.winkler@qse.ifs.tuwien.ac.at
http://qse.ifs.tuwien.ac.at
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