Utrecht University

Faculty of Science
Department of Information and Computing Sciences

An introduction to Design Science

Advanced Research Methods 2018-2019

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Learning objectives

- Explore the characteristics of the design science framework
- Specify research goals and research questions
- Explore basic characteristics of experimental design

Experimental design in a nutshell

For assignment A1:

Some notions on experimental design are useful before selecting the artefacts for the comparative experiment

After selecting a topic, choose one research artefact (i.e., technique, method, framework, etc.) within the topic you have selected. The artefact you select should fulfil the following requirements:

1. It is possible to compare the selected artefact with similar artefacts
2. There are scientific publications with a clear presentation of the design of the technique, method, or framework within the topic that you have selected
3. There are publications presenting examples of the application of the technique, method, or framework. If there are no examples available, they should be derivable.
4. There is a clear need to do research in the topic you have selected. There is related work or similar designs to the technique, method, or framework you have selected.
5. There is a clear need for conducting empirical evaluations for the technique, method, or framework you have selected. There is a clear need to investigate the selected technique, method, or framework in a certain context.

The motivation document consists of the following parts (1 to 2 pages)

1. Student names and numbers
2. Selected topic
3. One to two paragraphs with the motivation. Why are you interested to do research about the selected artefact/topic? Can you identify a possible technological impact?
4. What kind of variables could be validated? Please identify qualitative and quantitative variables.
5. One to two paragraphs with the expectations of the team. What do you expect to learn when designing this research project? Which grade do you want to get for the research assignment? What is your plan to maximise the chances to receive the desired grade? What do you need to achieve your goal?

Experiment
a.k.a. controlled experiment

Empirical evaluation that manipulates one factor or variable of the studied setting.

Based in randomization, different treatments are applied to or by different subjects, while keeping other variables constant, and measuring the effects on outcome variables.

It is mostly done in a laboratory environment, which provides a high level of control.

When experimenting, subjects are assigned to different treatments at random

Experiment

Quasi-experiment: The assignment of treatments to subjects cannot be based on randomization, but emerges from the characteristics of the subjects or objects themselves

In experimental studies, methods for statistical inference are applied with the purpose of showing with statistical significance that one method is better than the other (theme 3 of the course)

Experiment vs Case study vs Survey

Strategy	Design type	Qualitative / Quantitative
Survey	Fixed	Both
Case Study	Flexible	Both
Experiments	Fixed	Mainly quantitative

Experiment

Advantages

Control of subjects, objects and instrumentation

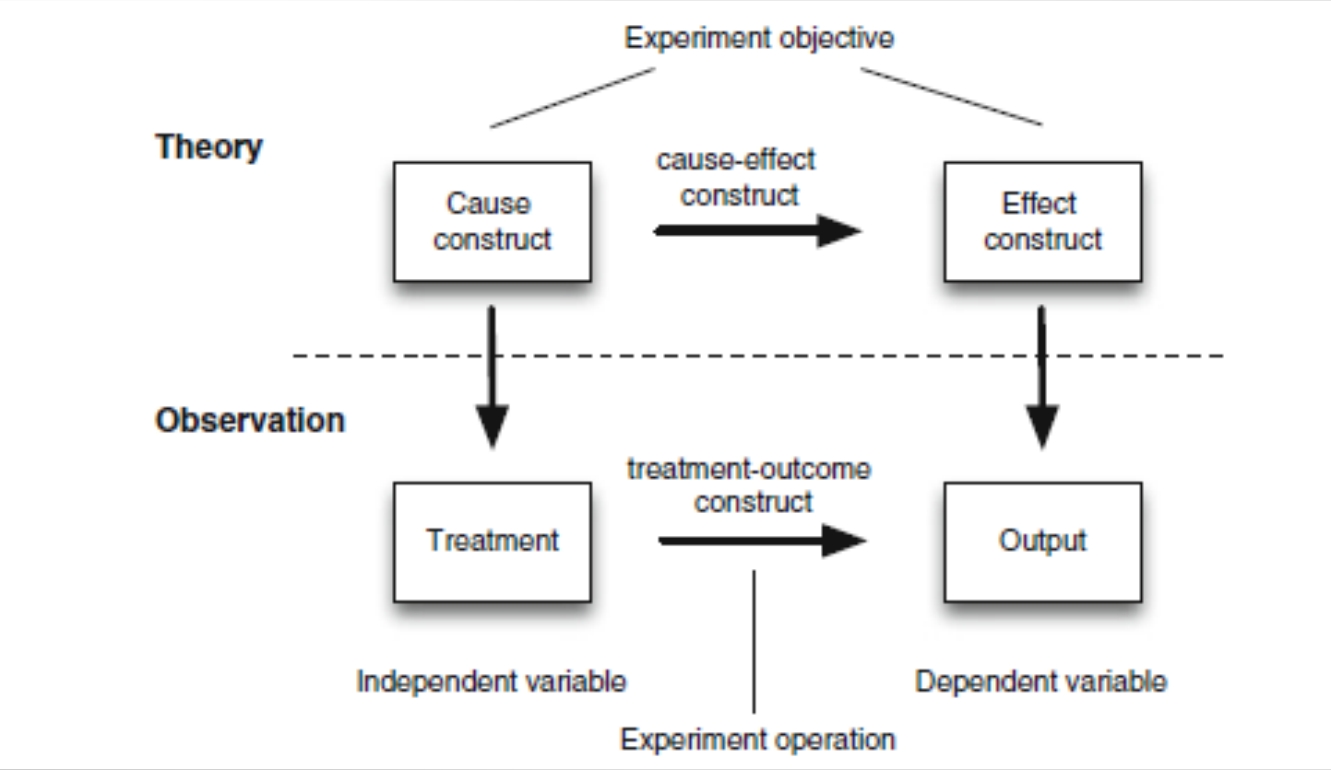
It is possible to draw general conclusions if you get significant differences

Ability to perform statistical analysis using hypothesis testing methods

Opportunities for replications in other settings

Experiment principles

The main objective is to evaluate hypotheses or relationships



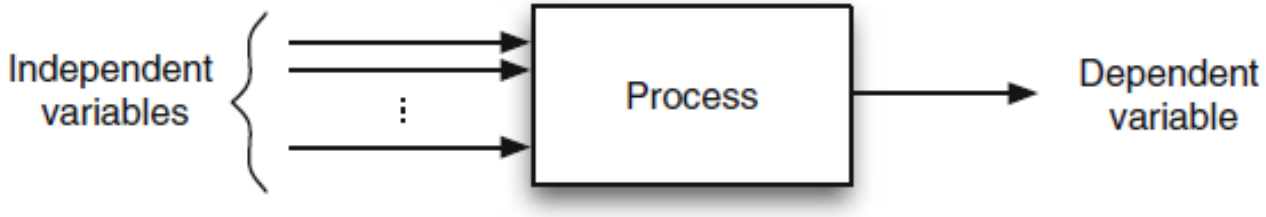
This topic will be further developed in week 49

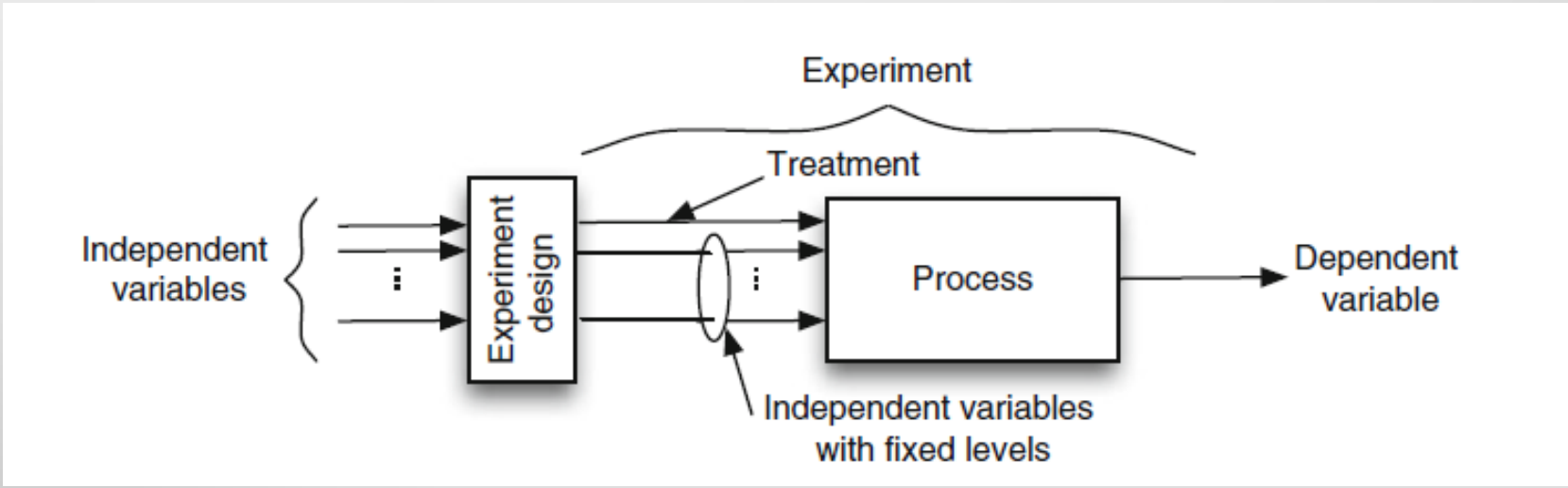
Variables

We want to study the outcome when we vary some of the input variables to a process. There are two kind of variables in an experiment: independent and dependent variables

Dependent variables: variables that we want to study and see the effect of the changes in the independent variables

Independent variables: variables that are manipulated and controlled. They affect the dependent variables


Independent
variables
Process
Dependent
variable


Experiment
Treatment
Independent
variables
Experiment
design
Process
Dependent
variable
Independent variables
with fixed levels

Example: MDD vs traditional SW development

"The goal of this experiment is to compare the MDD paradigm with traditional software development methods for the purpose of filling the existing gap in empirical evidence about MDD. The focus is placed on the differences that appear when building a system from scratch. Of all the existing differences, we focus on product attributes, as well as on developer comfort and workload. The experiment is conducted from the perspective of researchers and practitioners interested in investigating how much better MDD is than traditional software development methods"

Download: http://www.sciencedirect.com/science/article/pii/S0950584915000488

Good example of experimental report

Variables of the example

Independent variables: development method (traditional method vs MDD)

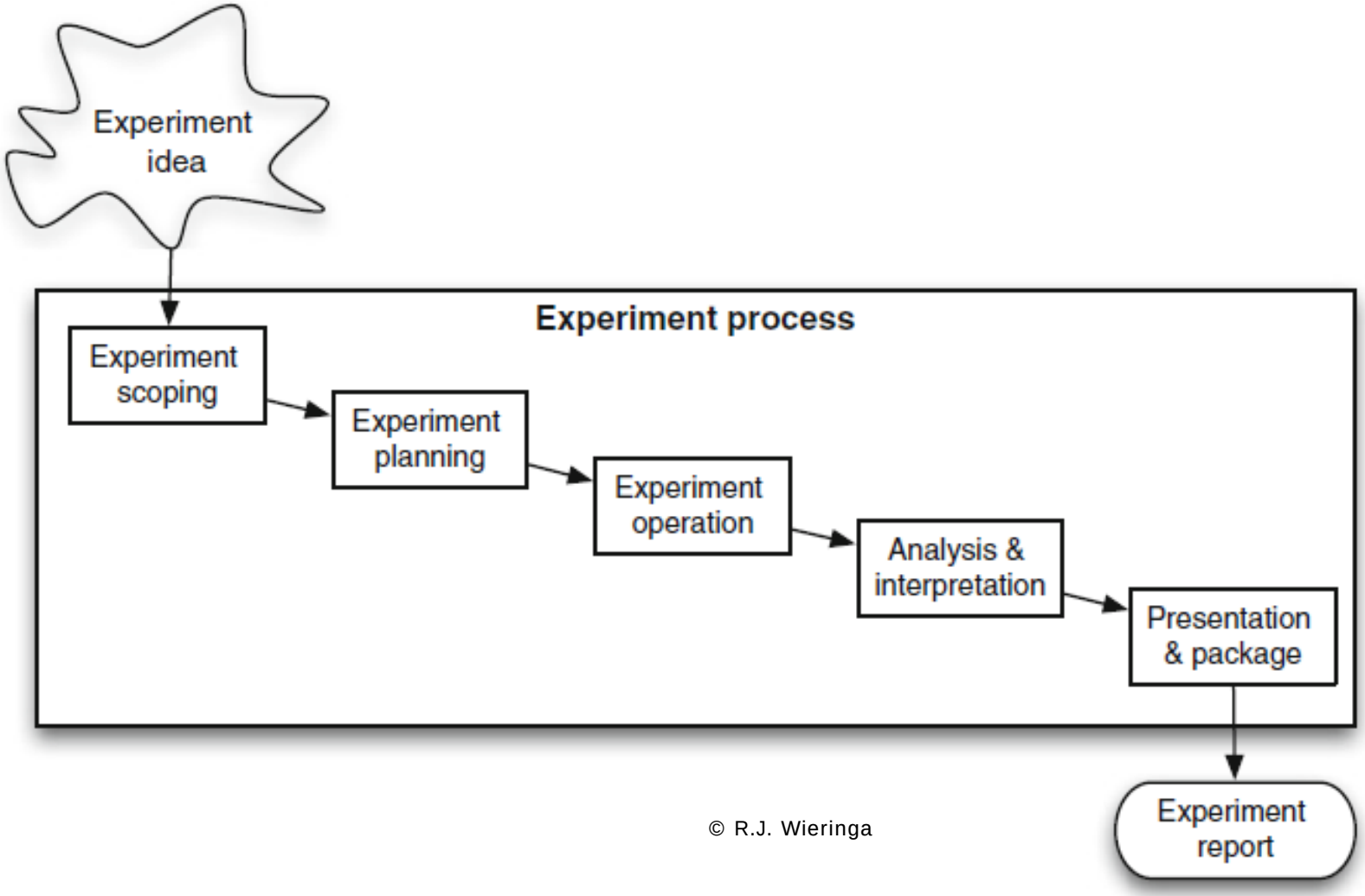
Dependent variables: Accuracy, effort, productivity, satisfaction

Variables

Independent variables are called factors
A treatment is one particular value of a factor

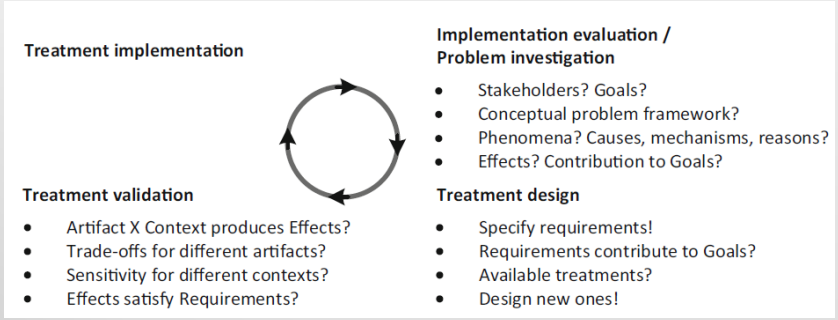
In the previews example, the treatment is the development method (traditional or MDD)

Experimental process
A general overview

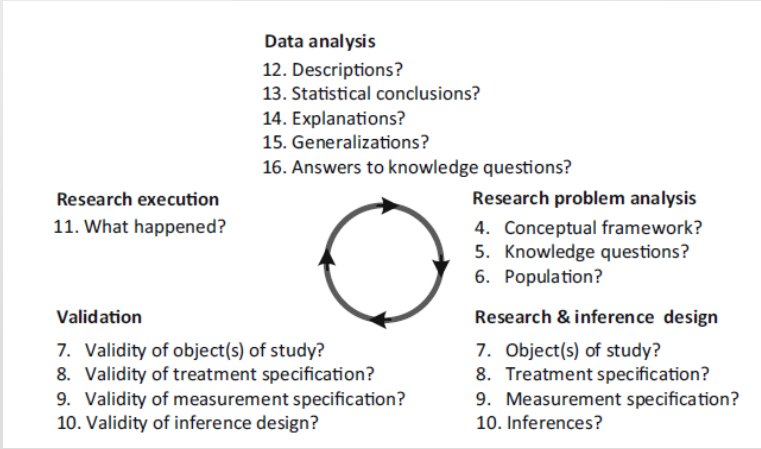


Experimental design

We have two artefacts that we want to test
We want to evaluate the artefacts in context: Design science!



Design cycle: for your master thesis (maybe), we don't have the artefacts



Empirical cycle: for the ARM course, you choose your favourite artefacts!

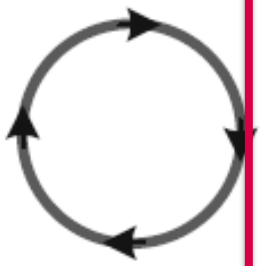
E

Data analysis

12. Descriptions?
13. Statistical conclusions?
14. Explanations?
15. Generalizations?
16. Answers to knowledge questions?

Research execution

11. What happened?



Research problem analysis

4. Conceptual framework?
5. Knowledge questions?
6. Population?

Validation

7. Validity of object(s) of study?
8. Validity of treatment specification?
9. Validity of measurement specification?
10. Validity of inference design?

Research & inference design

7. Object(s) of study?
8. Treatment specification?
9. Measurement specification?
10. Inferences?

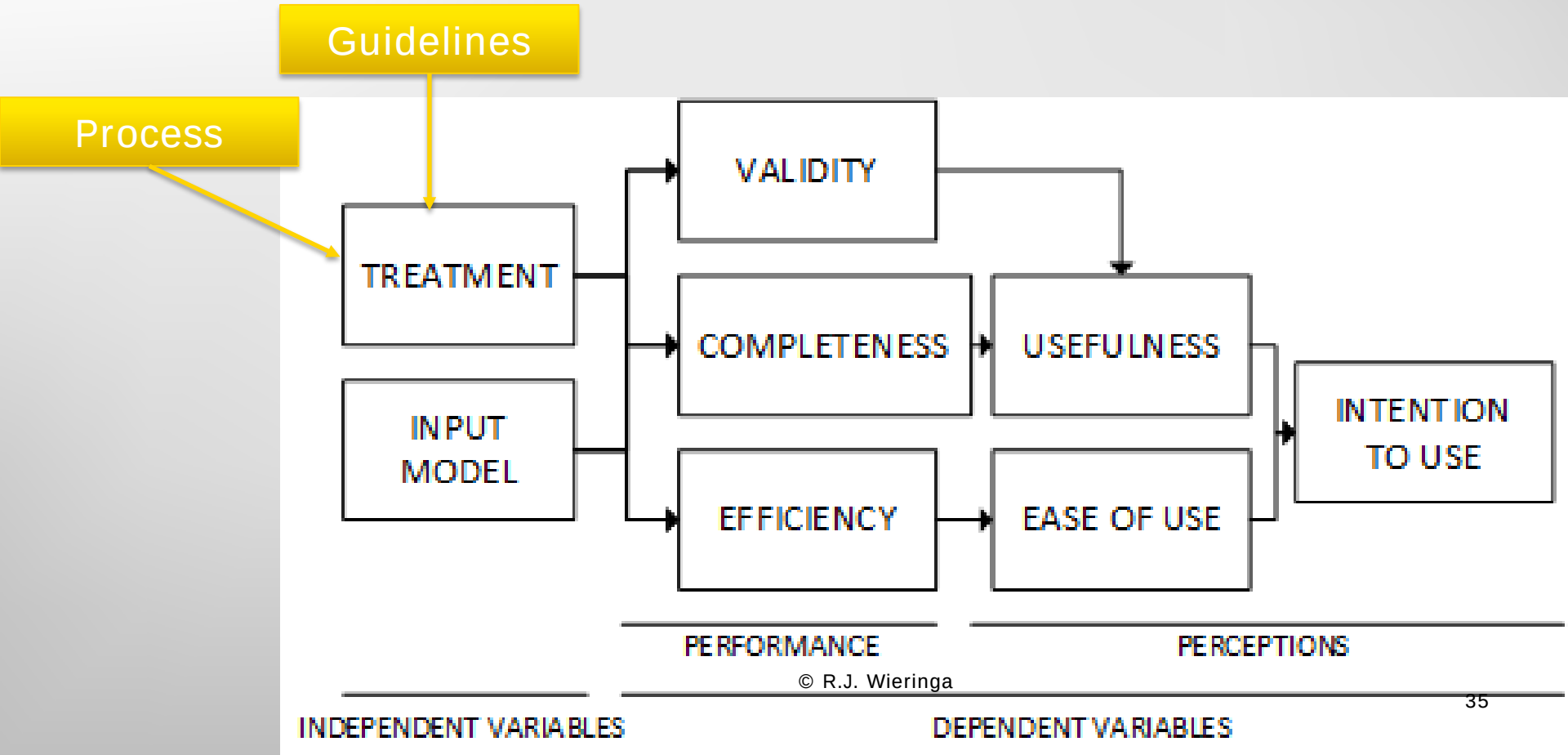
Check existing frameworks or methods for validation

- We are the researchers of this project. What to test?
- It is convenient to check existing frameworks or methods for validation

Source: Daniel L. Moody,The method evaluation model: a theoretical model for validating information systems design methods. Proceedings of the 11th European Conference on Information Systems, ECIS 2003, Naples, Italy 16-21 June 2003

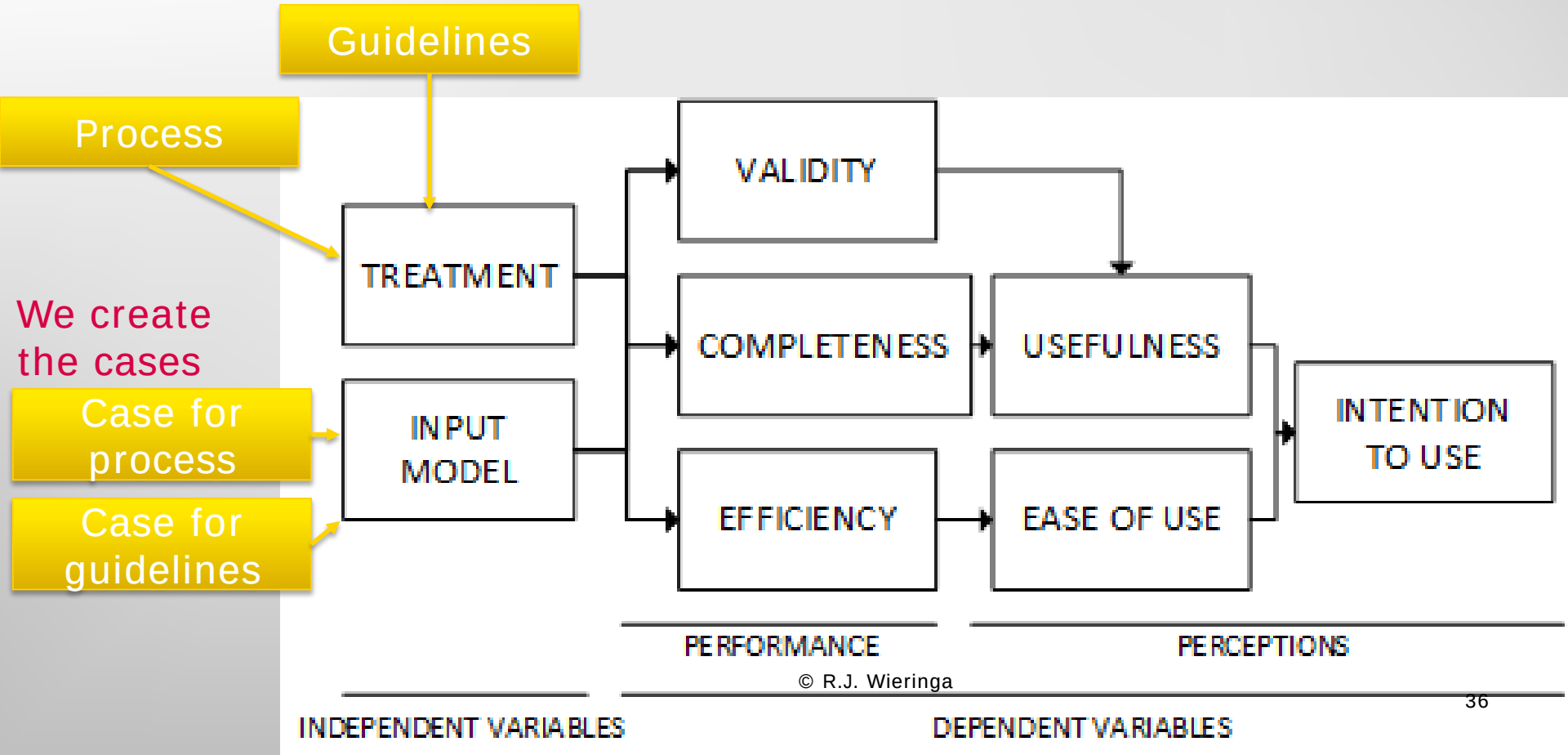
Example

Selected artefacts to test



Example

Selected artefacts to test



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Coaching is unlocking a person's potential to maximize their own performance. It's helping them to learn rather than teaching them.

~ John Whitmore ~

"I expect you all to be independent, innovative, critical thinkers who will do exactly as I say!"

Expectation management

What do you expect from your supervisor/teacher?
What can I (as a supervisor) expect from my students?

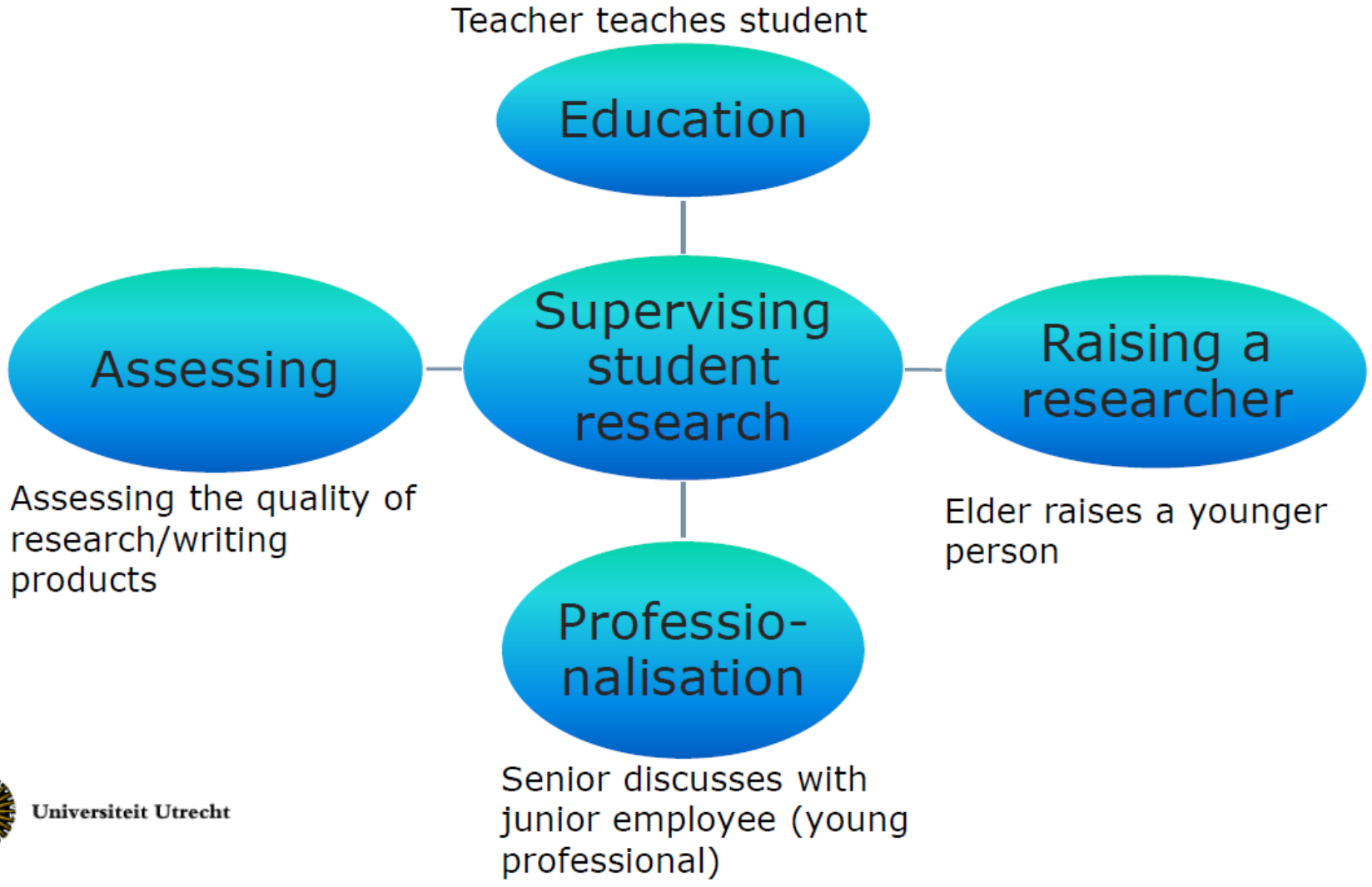
STUDENTS' PROBLEMS:

- Prior knowledge: insufficient research skills
- Research Question: how to define a good research question (unaware of what's a good question)
- Writing: writing the first version, unawareness of successful writing strategies

SUPERVISOR'S PROBLEMS:

- Role taking (teacher, educator, coach, assessor)
- 'Tool kit' (switching in style, role, degree of steering)
- Efficiency & effectivity (planning, clear communication/ expectations, effective feedback)

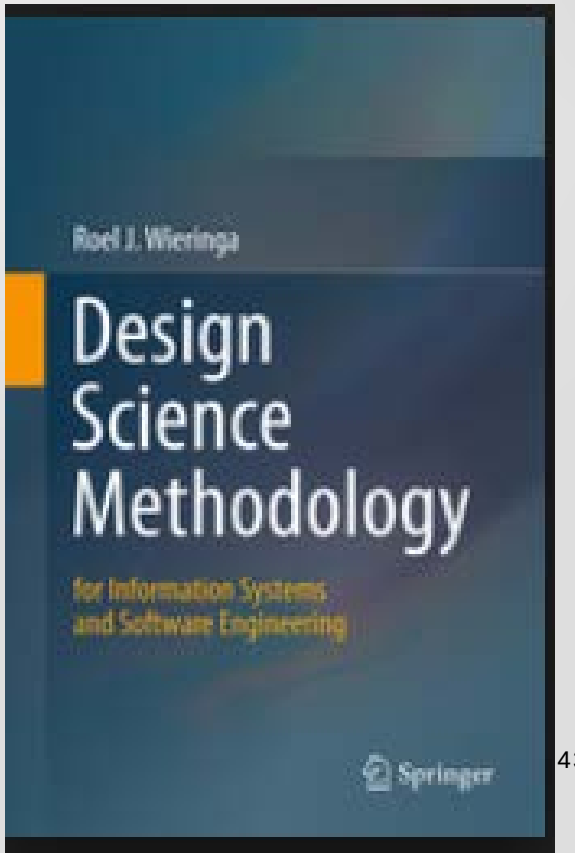
Roles of the supervisor



Basic structure of a meeting

- Start
  Atmosphere, relation, initiative, expectations
- Planning / Agenda setting
  Objectives meeting
- Core business (content)
  1. Discussing progress in research
  2. Content (concept of research plan or report)
  3. Future: research process and next version report
  4. Additional topics (e.g. expectations)
- Closing
  summarizing, checking, smart goals

1. What is design science
2. Research goals and research questions



Goal of the course

Introductory lesson to help you do your research projects (e.g. Bachelor thesis, Master thesis, etc.,)
Improve your capability to justify your solution
Help you structure your research

Improves your problem-solving capability
But not a creativity course

Reality check

What kind of problems?

Business Information Technology master thesis at the University of Twente:
http://essay.utwente.nl/view/programme/60025.html

Bachelor and master theses UU:
http://studenttheses.library.uu.nl/

Can these two kind of problems be linked?

Two kinds of research problems (projects)

(1) Design problems

- Improve something, design something , how-to-do something
- Problem, design of a treatment, validation of the treatment
- Design cycle
- Improvement is the goal, utility is the criterion
- Knowledge is a side-effect
- “Technical research problems’’

(2) Knowledge questions

- Describe, explain, predict
- Questions, research design, research execution, data, analysis
- Empirical research cycle
- Knowledge is the goal, truth is the criterion
- Utility is a side-effect

Focus on justification

This is not a creativity course
Not about how to be original

- You can be creative with your classmates at the moment to select a research artefact for the assignment
- In the future, your supervisor will provide you with tools to be creative at the moment to find a research project

- The course is about how to justify and report your research results
- Why would anyone use your design? There are many other designs.
- Why would anyone believe your answers? Opinions are cheap.
- Your report must have a logical structure
- This also helps you to organize the project itself.

- You can be creative when reporting results and designing your research

Questions?

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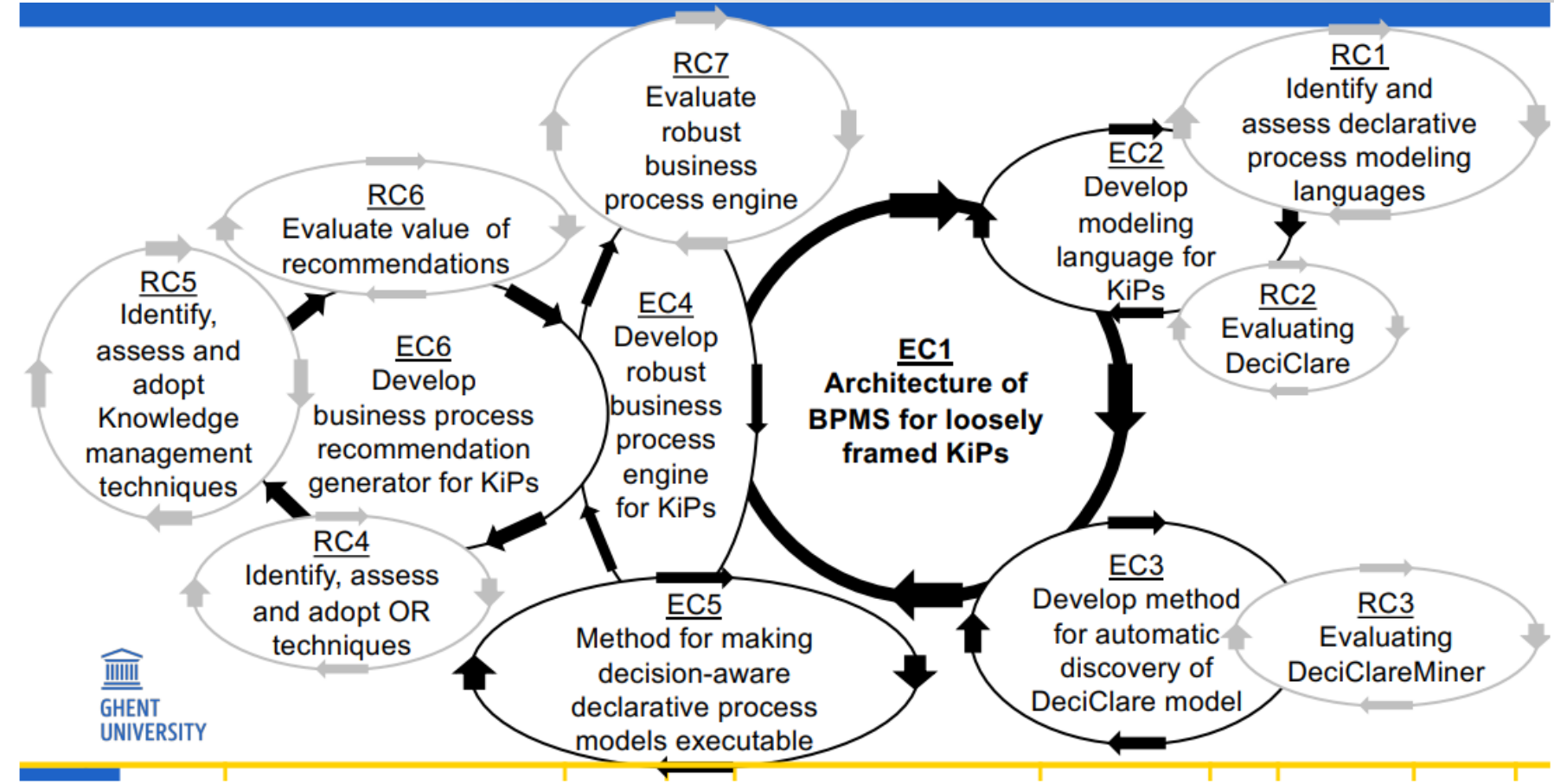
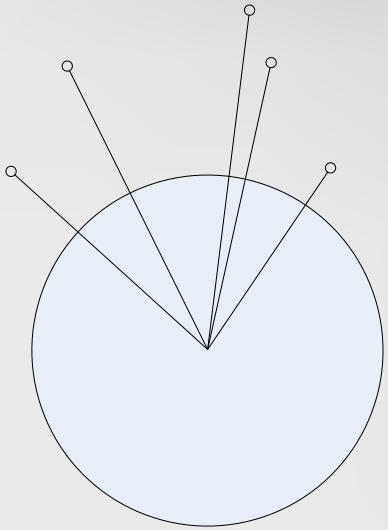
1 What is design science?

Design science is the design and investigation of artifacts in context



SUPPORTING AND ASSISTING THE EXECUTION OF LOOSELY FRAMED AND KNOWLEDGE-INTENSIVE PROCESSES. Steven Mertens, Frederik Gailly and Geert Poels



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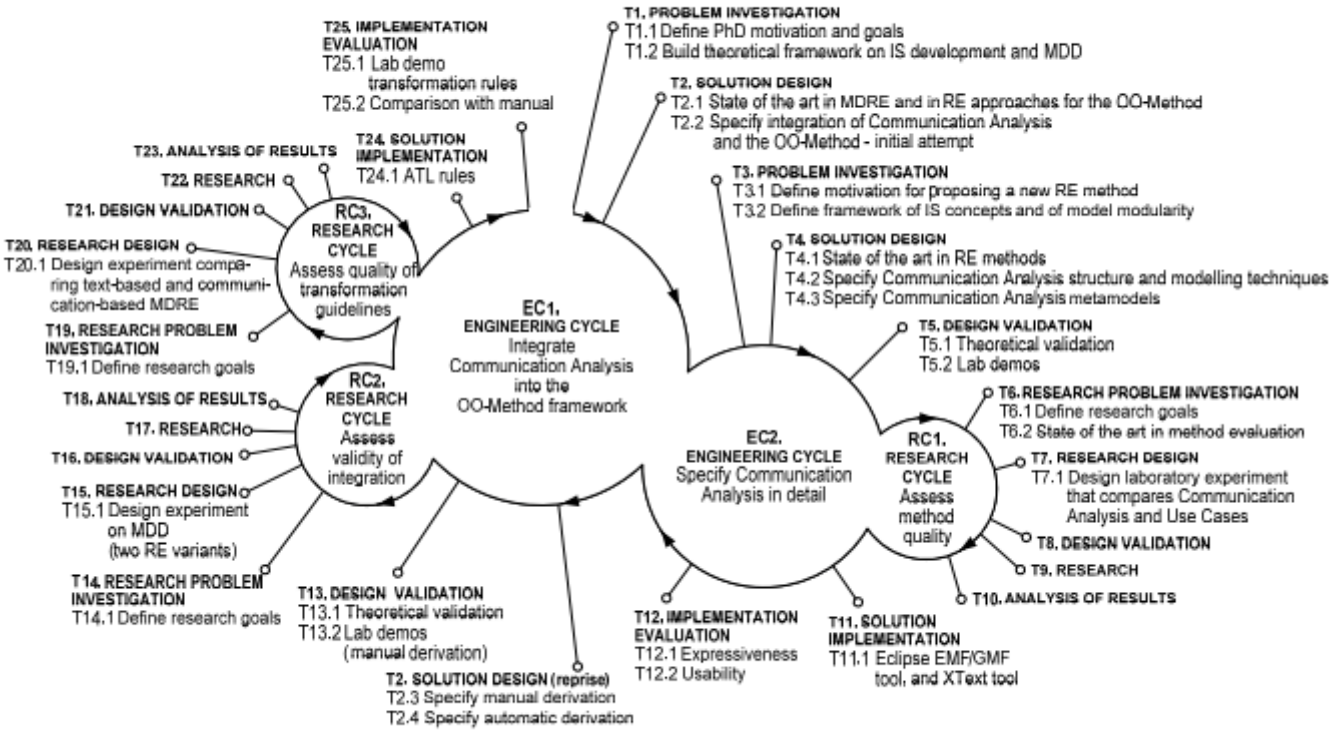


Figure 6. Research structure in terms of regulative cycles

España (2011), METHODOLOGICAL INTEGRATION OF COMMUNICATION ANALYSIS INTO A MODEL-DRIVEN SOFTWARE DEVELOPMENT FRAMEWORK

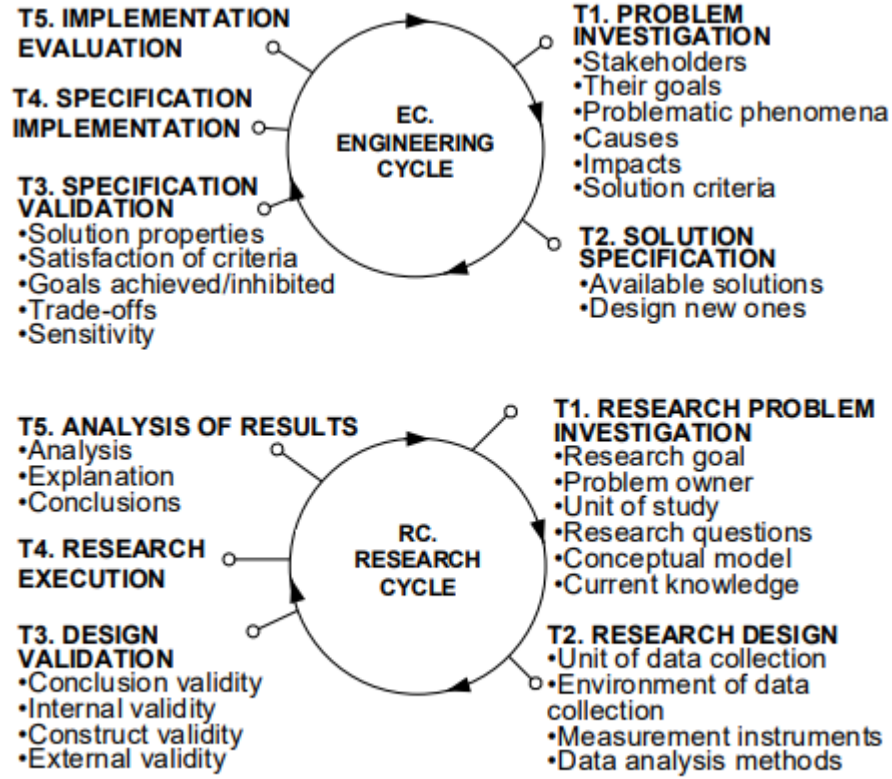
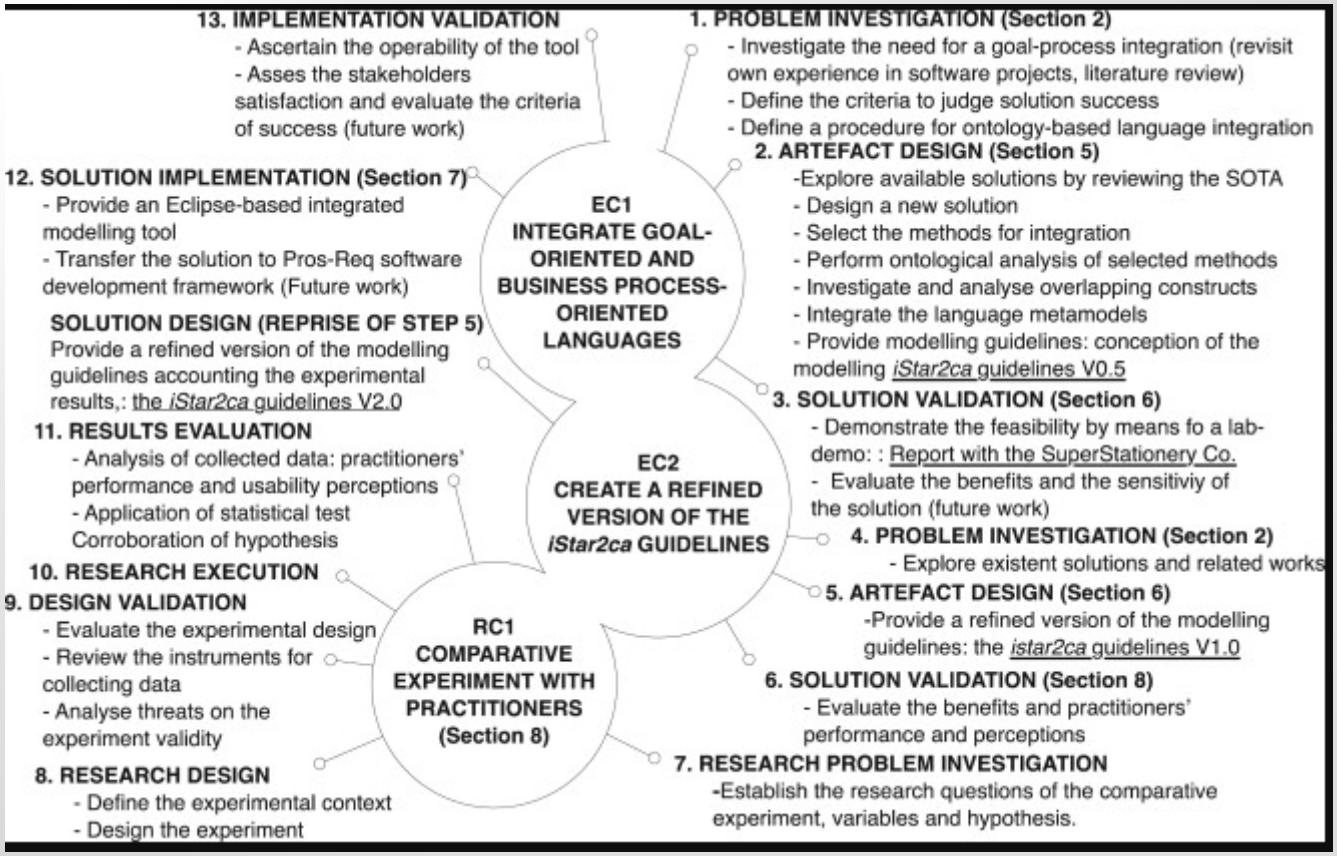


Figure 1.1 Design science as a regulative cycle

Villanueva (2016). An agile model-driven method for involving end-users in DSL development



GoBIS: An integrated framework to analyse the goal and business process perspectives in information systems
Authors: Ruiz et al. Information Systems Journal (2015)

Reality check: What is the artifact and what is the context?

Business Information Technology master thesis at the University of Twente:
http://essay.utwente.nl/view/programme/60025.html

Bachelor and master theses UU:
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Without a context, an artifact does nothing

1.2 Research problems in design science

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Research problems in design science

To design an artifact to improve a problem context

Problems & Artifacts to investigate

Knowledge, Design problems

To answer knowledge questions about the artifact in context

Design software to estimate Direction of Arrival of plane waves, to be used in satelite TV receivers in cars	• *Is the DoA estimation accurate enough in this context?* • *Is it fast enough?*
Design a Multi-Agent Route Planning system to be used for aircraft taxi route planning	• *Is this routing algorithm deadlock-free on airports?* • *How much delay does it produce?*
Design a data location regulation auditing method	• *Is the method usable and useful for consultants?*

Artifact of a design problem = the artifact **to be** designed

Artifact of a knowledge question = the artifact **about which** we ask the knowledge question

Heuristics

Design problems

Call for a change of the world

- Solution is design
- Many solutions
- Evaluated by utility
- Many degrees of utility
- What is useful depends on stakeholder goals

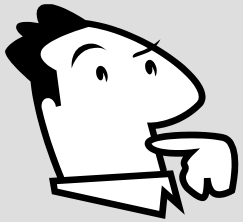
Doing

Knowledge questions

Ask for knowledge about the world

- Answer is a proposition
- One answer
- Evaluated by truth
- Many degrees of certainty about the answer
- What is considered “true” does not depend on stakeholder goals

Thinking



Discuss with your colleagues

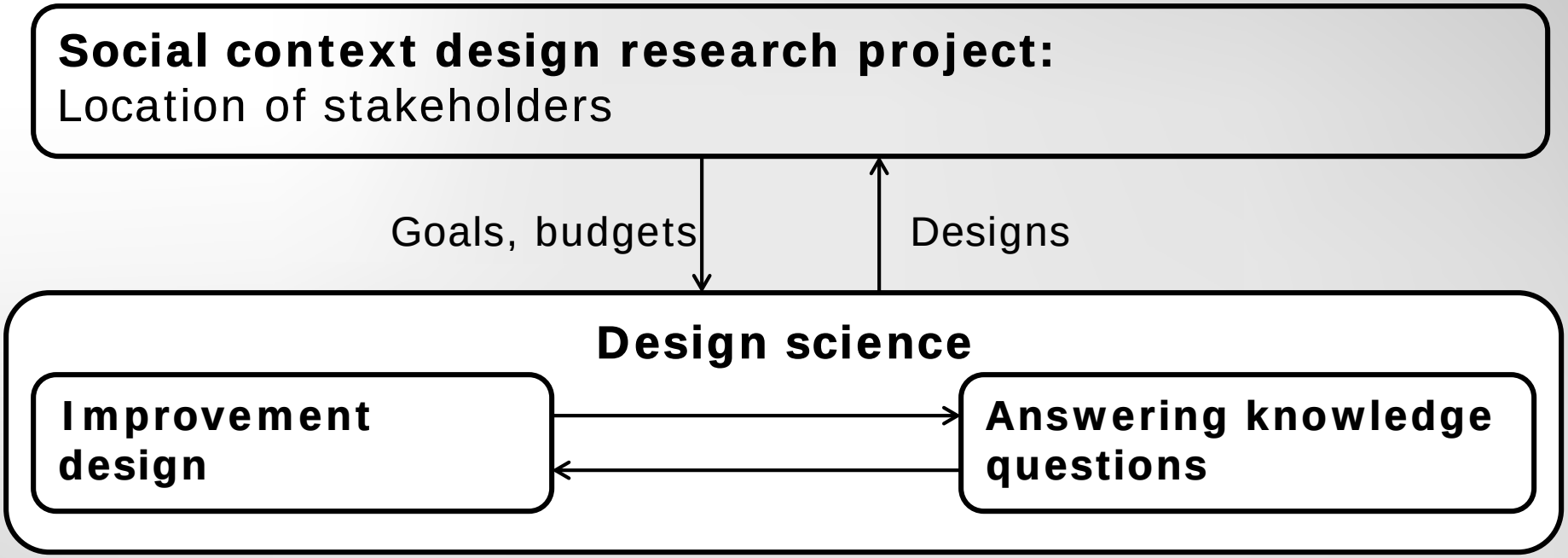
Ingredients for your research assignment

What research problem(s) are you investigating?
Artifact and context

Note
In the context of the ARM course we are going to conduct a knowledge-oriented research project, which is motivated by a design problem. In the future you can be confronted with the challenge to conduct any of these two type of research projects

1.3 The context of a design science project

The social context of design research



"Design a estimation system to be used in cars":
Stakeholders: Researchers, Sponsor, component suppliers, car manufacturers, garages, car passengers

"Design an assurance method for cloud service provider data compliance".
Stakeholders: Sponsor, consultants (end-users), researchers, Clients.

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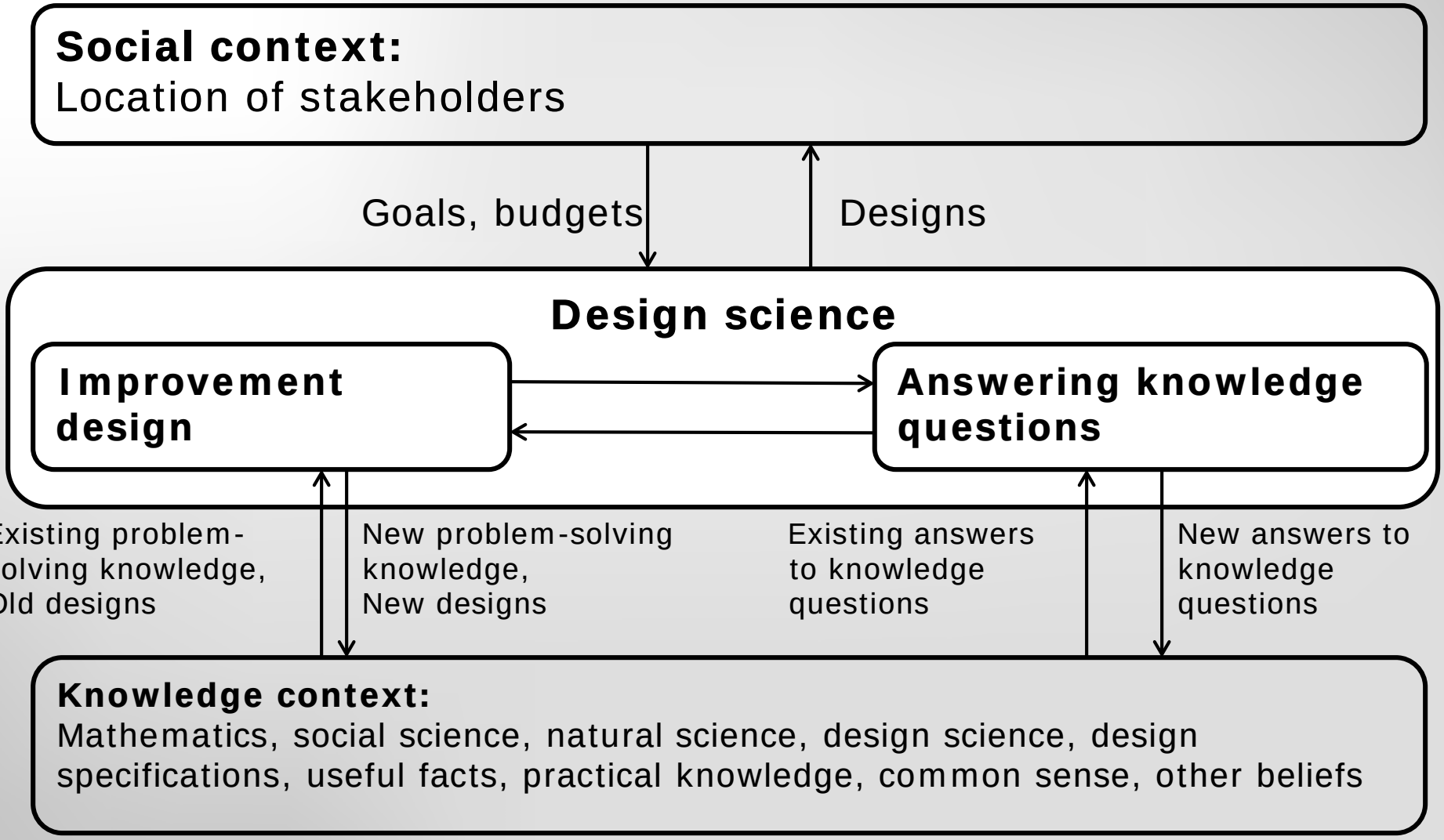
The knowledge context of design research



Knowledge sources

- Scientific literature
- Scientific, peer reviewed journals and conferences (math, natural science, social science, design sciences)
- Technical literature
- Design specifications, manuals
- Professional literature
- Non-peer reviewed professional magazines, trade press, marketing literature, white papers (useful facts and opinions, practical knowledge, common sense)
- Oral communication
- Colleagues, supervisors, practitioners (useful facts and opinions, practical knowledge, common sense, other beliefs)

Discussion point
- How is the channel managed?
- How does the source ensure quality of information?

What about the Web?

- The Web is a communication channel, not a source of information
- Sources are more diverse
- Scientific literature
- Technical literature
- Professional literature
- On-line databases
- Social networks
- Did the information survive
- Empirical tests?
- Critical judgment of peers?

Your research aims at theories

- Knowing the relevant properties of a particular artifact in a particular context is not enough
- Theories should be general, so you can use them for prediction
- Theories should explain, so that you understand why phenomena occur

- If the artifact prototype that you built disappears, what is the knowledge remains?
- Tested, critiqued knowledge

Main points: What is design science

- Design science is the design and investigation of artifacts in context
  - Research problems are design problems or knowledge questions
  - Artifacts interact with their context to deliver a service
- The social context of a design science project consists of stakeholders and their goals and budgets, laws, processes, norms, expectations, etc.
- The knowledge context consists of scientific knowledge, design specifications, useful facts, practical knowledge, common sense, etc. You aim to contribute scientific theories.

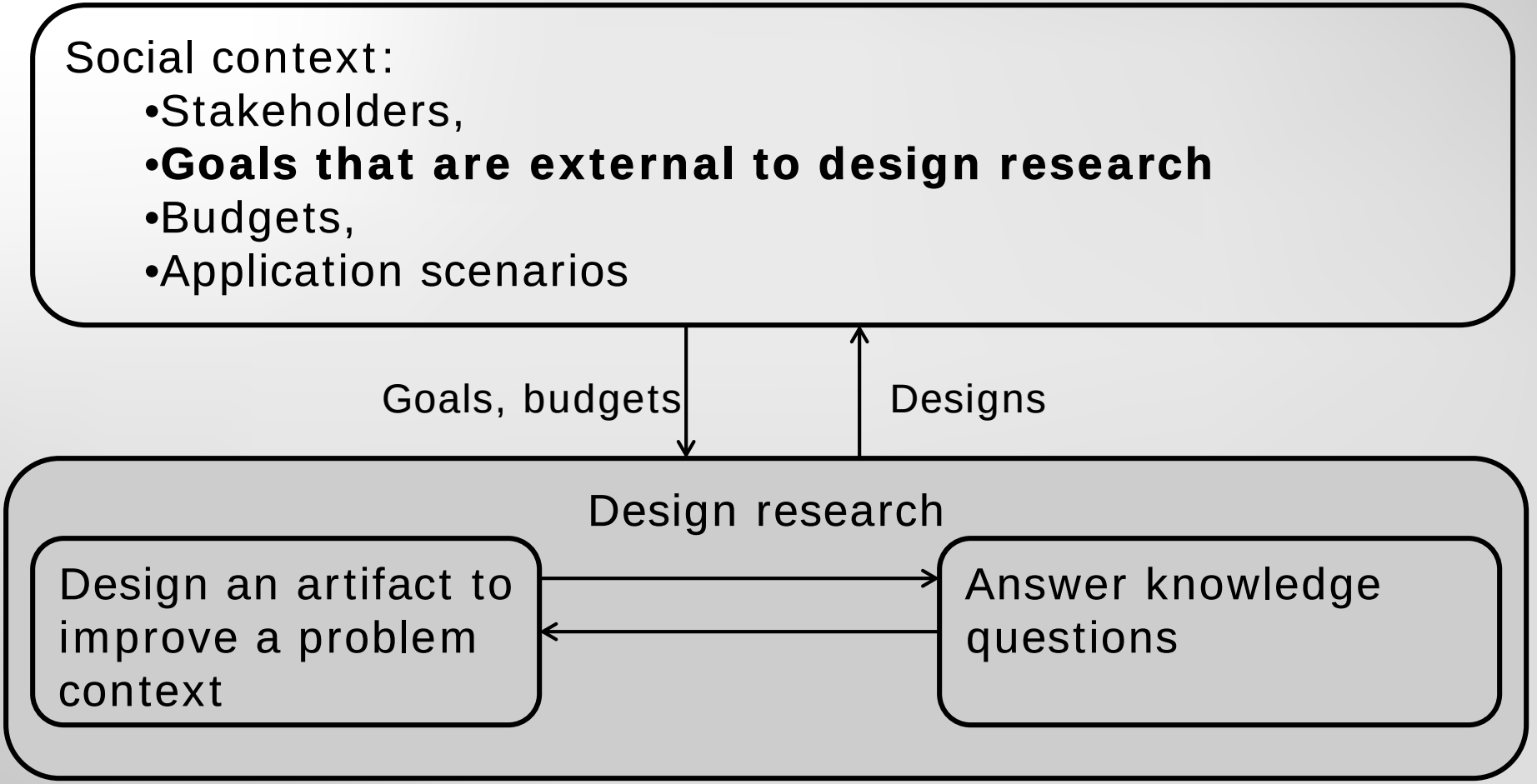
Activity
Motivation for your research project

- What is going to be delivered by your ARM project?
- What is new?
- Who are the stakeholders of your project?
- What are their goals?
- What knowledge will be produced by your project?
- What is new?

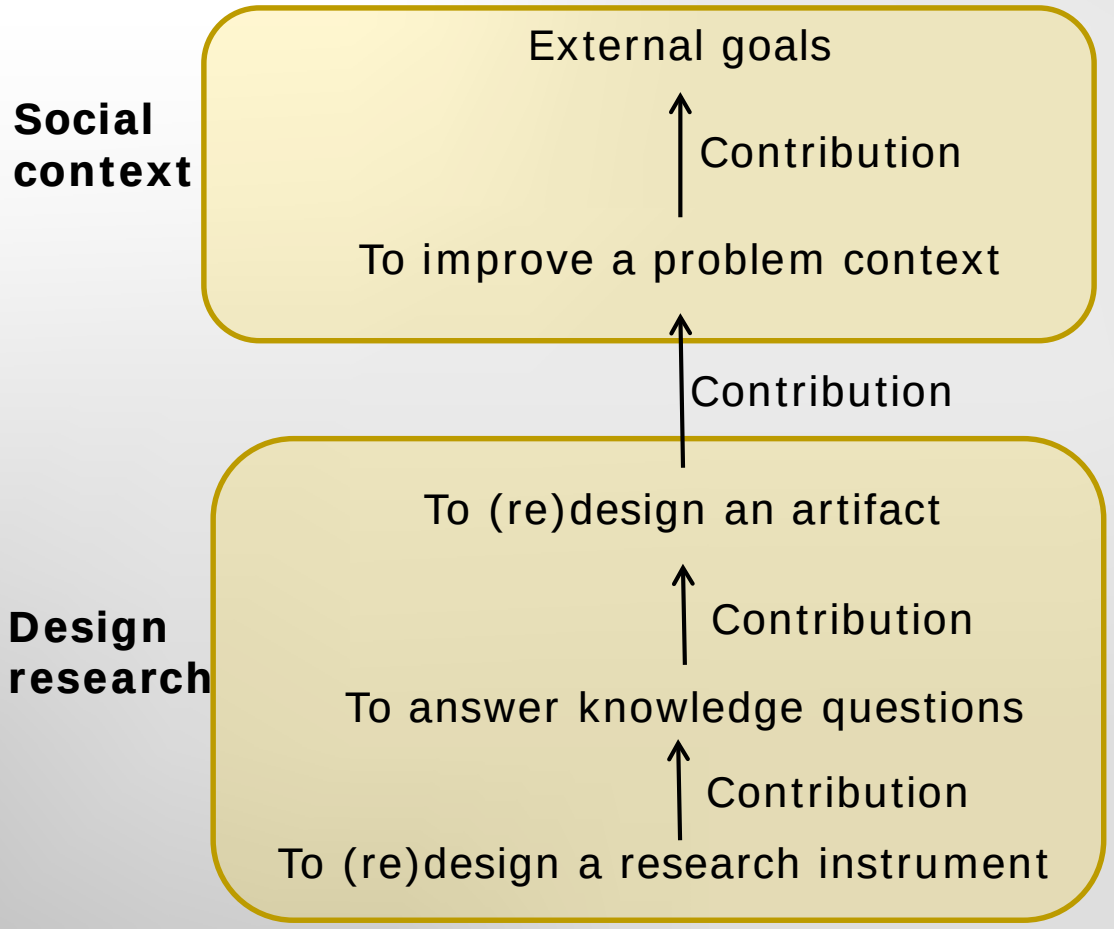
2. Research Goals and Research Questions

2.1 Research goals

External goals



Goal structure



Motivation of the research goal: friends, family, the government, sponsors, investors, etc. are interested in these.

A design **research goal** is the desired outcome of a research project, to which the research budget is allocated. Colleagues are interested in these.

Examples

Ucare

External goals:

- Reduce health care cost (government)
- Reduce work pressure, increase quality of care (health personnel)
- Increase quality of care, increase independence (elderly)
- Design goals
- Design a mobile home care system for use by elderly that provides:
  - Medicine dispensing
  - Blood pressure monitoring
  - Agenda
  - Remote medical advice

Two kinds of design research problems

To achieve the design goal, we need to answer research questions.

- Design problems
- A.k.a. technical research questions

Knowledge questions

- Analytical research questions: can be answered by analysis
- Empirical research questions: must be answered by collecting data

2.2 Design problems

Template for design problems

Improve <problem context>
by <treating it with a (re)designed artifact>
such that <artifact requirements>
in order to <stakeholder goals>

Improve my body / mind health
by taking a medicine
such that my headache disappears
in order for me to get back to work

Template for design problems

Improve <problem context>
by <treating it with a (re)designed artifact>
such that <artifact requirements>
in order to <stakeholder goals>

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External: Problem context and stakeholder goals

Template for design problems

Improve <problem context>
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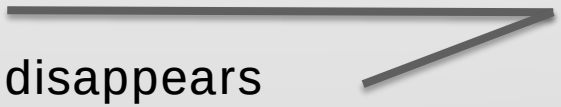


Design research problem: Artifact and its desired interactions

Template for design problems

Improve <problem context>
by <treating it with a (re)designed artifact>
such that <artifact requirements>
in order to <stakeholder goals>

Improve my body / mind health
by taking a medicine
such that my headache disappears
in order for me to get back to work

Particular problem

Improve home care
By a mobile support device
That provides some services …
So that cost are reduced etc.

General problem

2.3 Knowledge questions

Kinds of empirical knowledge questions

Empirical knowledge questions may be

1. descriptive or explanatory,
2. open or closed,
3. effect-related or requirement-related

First classification knowledge questions

Descriptive questions:
What happened?
When?
Where?
What components were involved?
Who was involved?
etc.

Journalistic questions,
Provide facts

Explanatory questions:
Why?

What has caused the phenomena? Which mechanisms produced the phenomena? For what reasons did people do this?

Example

Descriptive question: What is the performance of the Ucare system?

- Accuracy of output
- Reliability of communication infrastructure
- Usability of interfaces
- Etc. etc.

Explanatory question: Why does Ucare have this performance?

- Cause: data entrance at 03:00 causes the data to be lost
- Mechanism: because the hospital database server is down for maintainance at night and there is no fallback retention mechanism
- Reasons: Users feel free to enter data any time they are awake, and they are awake at 03:00.

Prediction problems

There are no predictive knowledge questions

- We cannot know the future
- Descriptive and explanatory questions are about the present and the past

But there are prediction problems

- How will the program behave when given this input?
- How would users behave when the program is changed?
- To solve a prediction problem, we need a general theory that tells us what happens

What concept relates to theory in the context of our ARM assignment?

Second classification of knowledge questions

Open questions (exploration):
No hypothesis about the answers.

- What is the execution time?

Closed questions (testing):
Specific, testable hypotheses as possible answers.

- Is execution time less than 1 second?
- Hypothesis: the execution time is less than 1 second.

Third classification: Design research questions

Effect question: Context X Artifact → Which Effects?

- Trade-off question: Context X Alternative artifact → Effects?
- Sensitivity question: Other context X artifact → Effects?

Requirements satisfaction question: Do these Effects satisfy requirements sufficiently?

Main points
Research goals & questions

A design science projects has goals that range from designing an instrument (lowest level) to contribution to external stakeholder goals (highest level).

Design problems have the form
Improve <problem context> by <treating it with a (re)designed artifact> such that <artifact requirements> in order to <stakeholder goals>

Knowledge questions may be analytical or empirical.
Empirical knowledge questions may be

- descriptive or explanatory,
- open or closed,
- effect-related or requirement-related

To answer prediction problems, we need general theories

Questions?

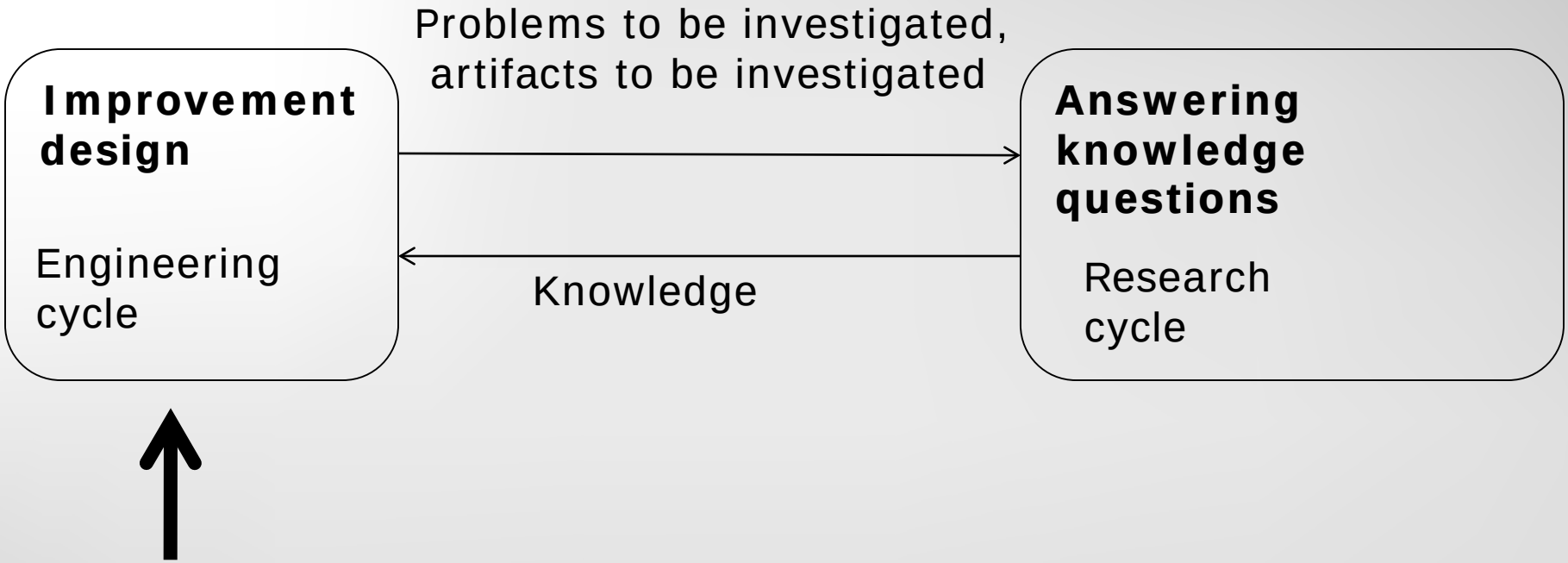
Empirical knowledge questions may be

1. descriptive or explanatory,
2. open or closed,
3. effect-related or requirement-related

Discuss with your colleague!

3 The design cycle

Activities in design science

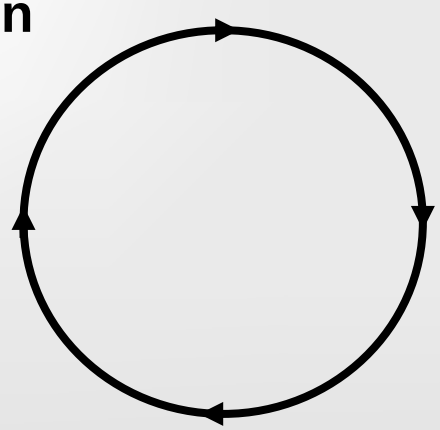


3.1 The design and engineering cycles

! = Action
? = Knowledge question

Engineering cycle

Treatment implementation



Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?

Treatment validation

- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design

- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

Treatment

We avoid the word “solution”.
Every solution is imperfect
… and introduces new problems

Specification and design

Treatments are designed, and the design is specified

- Designing is deciding what to do
- Specifying is documenting that decision

What is implementation?

Depends on who you talk to

- For a software engineer, this is writing and debugging a program until it works.
- For a mechanical engineer, this is assembling the physical machine until it works
- For the manager, this is introducing the machine in the organization until it works
- For a marketing department, this is selling the system

Implementation

Implementation = introducing an artifact in the intended problem context

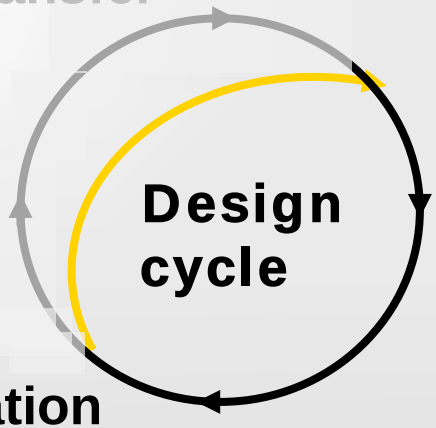
What this means depends on what your problem was

- For a software engineer: To construct software
- For a mechanical engineer: To construct physical machine
- For the manager: To change an organization
- For a marketeer: To sell a product

Utrecht University

Design cycle
Typical academic research project

Real-world treatment Implementation: Technology transfer



Real-world implementation evaluation = Real-world problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes, mechanisms, reasons?
- Effects? Positive/negative goal contribution?

Treatment validation

- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

Treatment design

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Validation versus evaluation

To validate a design for stakeholders is to justify that it would contribute to their goals before transfer to practice

- Predicted effects?
- Satisfaction of requirements?
- Requirements contribute to goals?

To evaluate an implementation is to investigate whether an implementation has contributed to to stakeholder goals after transfer to practice

- Stakeholders, goals?
- Effects?
- Contribution?

What is the difference?

Implementation evaluation research studies real-world implementations with respect to actual stakeholder goals
Real-world research

Treatment validation research uses a validation model to predict effects
Simulation

Main points The design cycle

- The engineering cycle is a rational decision cycle:
- Problem/evaluation: Look where you are and what you want to do;
- Design possible treatments;
- Validate treatments without executing them;
- Choose one and implement it;
- Evaluation/problem: Look where you are now and what you now want to do.

The design cycle is the preparation for action:
Problem-design-validation.

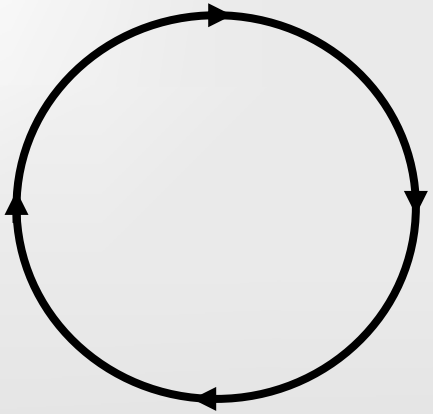
- The cycles can be organized in many different ways.
- All of them must allow you to justify your choices afterwards.
- The engineering cycle allows you to justify your actions (validation) and to learn from their effects (evaluation)

4. The empirical cycle

! = Action
? = Knowledge question

Engineering cycle

Treatment implementation



Implementation evaluation = Problem investigation

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena?
  - Causes, mechanisms, reasons?
  - Effects?
  - Positive/negative goal contribution?

Treatment validation

- Context & Artifact → Effects? Why?
- Trade-offs for different artifacts? Why?
- Sensitivity for different Contexts? Why?

- Effects satisfy Requirements? Why?

Treatment design

- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!

Validation research questions are the same as implementation evaluation questions

But the goal is to validate new technology,
Not to evaluate implemented technology

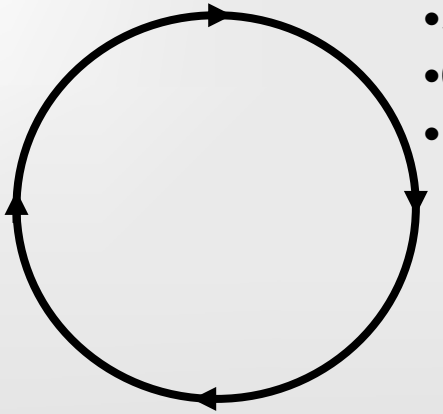
We find the validation research questions by analyzing treatment requirements (next slide)

! = Action
? = Knowledge question

Engineering cycle

Treatment implementation

Implementation evaluation = Problem investigation



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- Sensitivity for different Contexts? Why?
- Effects satisfy Requirements? Why?

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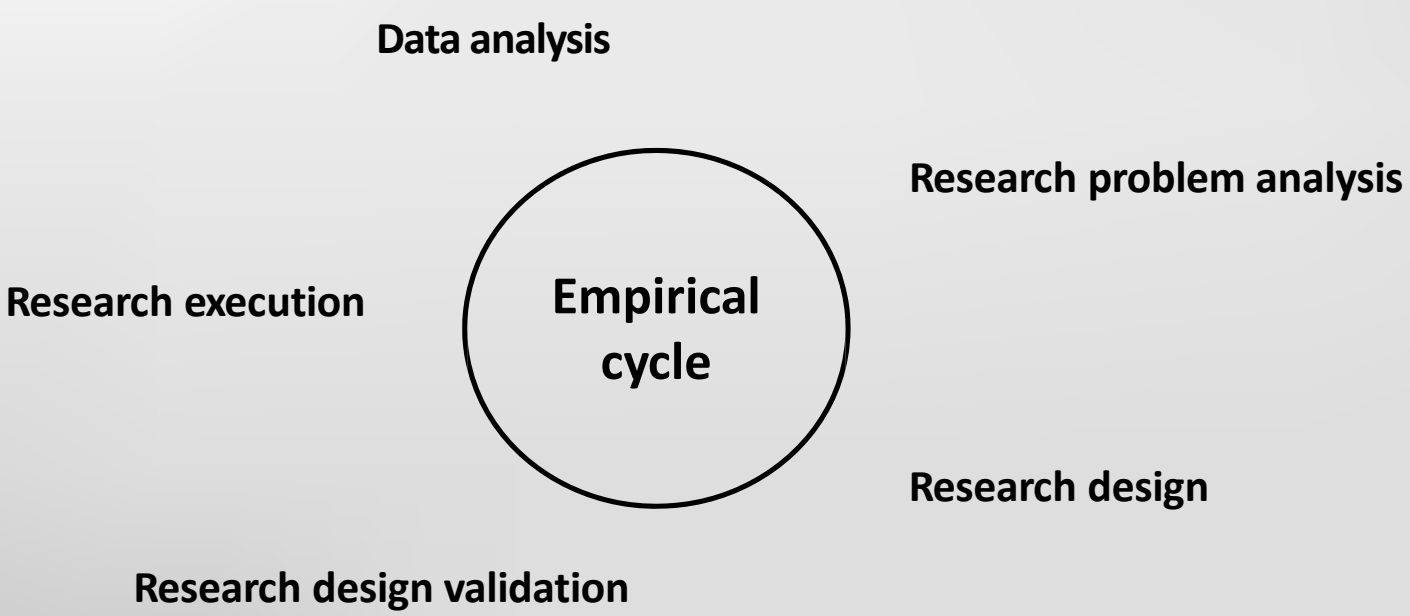
Activity

Draw the tasks of the empirical cycle for your ARM project

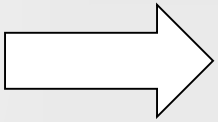


To get answerable research questions, we need to operationalize the requirements!

Ucare requirements Functions

- Medicine dispensing
- Blood pressure monitoring
- Agenda
- Remote medical advice

Usable by elderly and medical personnel
Reliable
Safe
Cheap



Validation research questions

- *Does it work?*
  - *Functions*
    - *Does it perform the medicine dispensing functions?*
    - *Does it perform the blood pressure monitoring functions?*
    - *Etc.*
  - *Is it usable by elderly and medical personnel?*
  - *Is it reliable?*
  - *Is it safe?*
  - *Is it cheap?*
- *What if we change the design?*
- *What if we vary the context?*

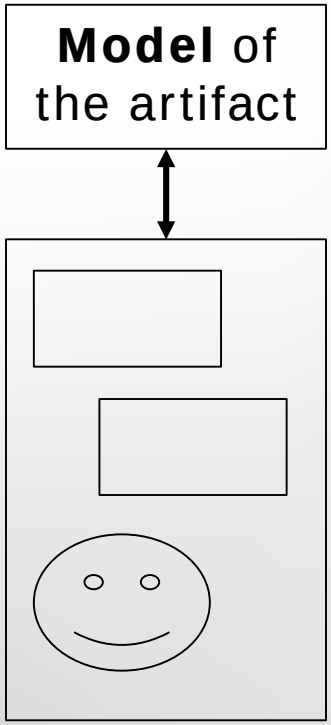
The fundamental problem of validation

We investigate the artifact outside its natural implementation context
The artifact has not been implemented yet.
It has not been transferred to the real-world problem context yet

- So we study it in the lab
- Or we do a pilot study in the real world

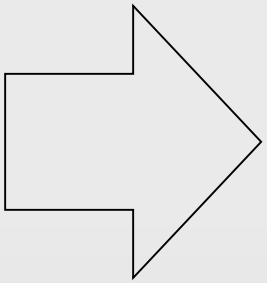
These are more or less realistic models of a real-world implementation

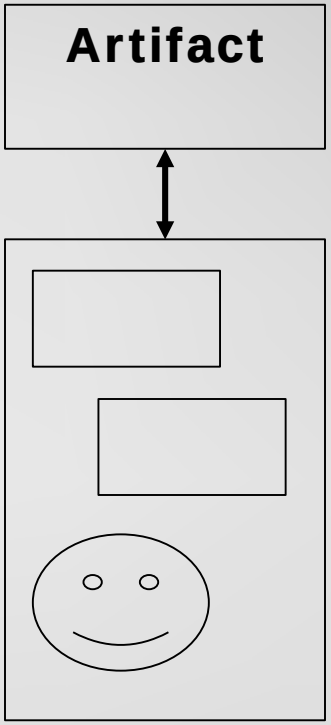
Validation models



Model of problem context (systems, stakeholders)

Representation





Problem context (systems, stakeholders)

Fig 7.2

What is a model?

An **analogic model** is an entity that represents entities of interest, called its **targets,** in such a way that questions about the target can be answered by studying the model.

Examples

http://en.wikipedia.org/wiki/MONIAC_Computer
http://en.wikipedia.org/wiki/Scale_model
http://en.wikipedia.org/wiki/Miniature_wargaming
http://en.wikipedia.org/wiki/Simulation

Example validation models

- *A software prototype interacting with a simulated environment*
- *A class of students using a new software engineering method in a project that simulates a real-world project*
- *A researcher using an experimental method to solve a real-world problem*
- *Ucare*

Nurses imagining how the system would function
Elderly using a prototype in their home

Similarity

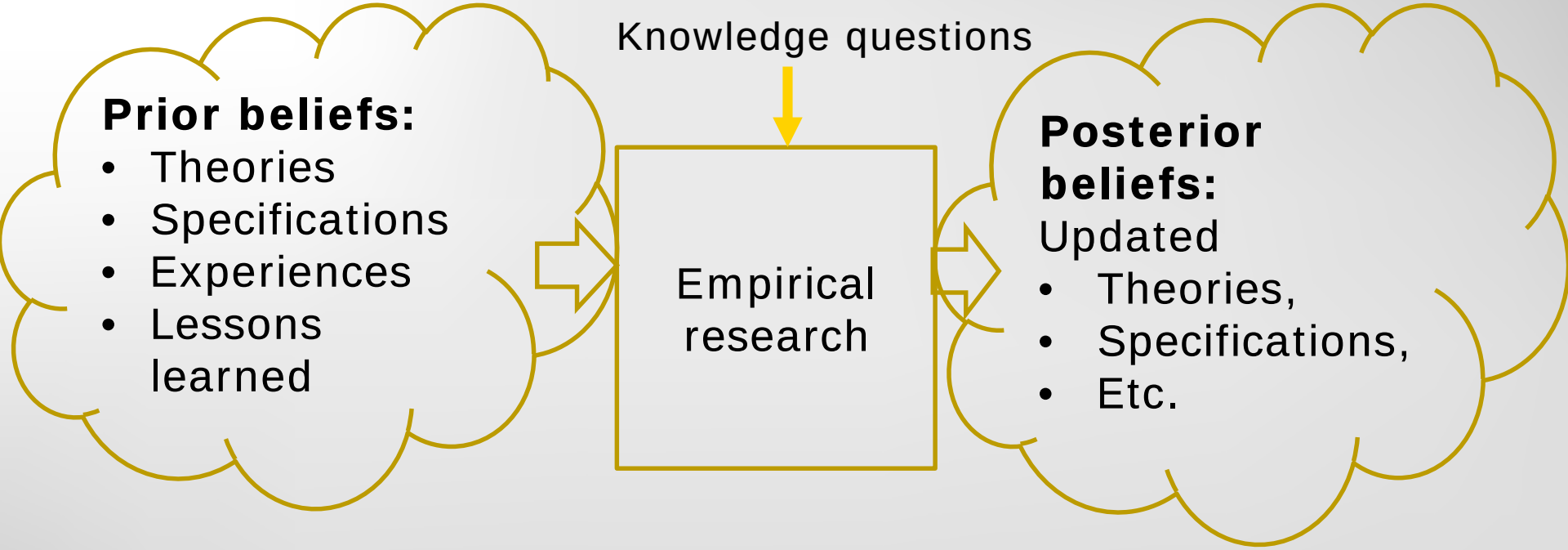
How reliable is the generalization from the validation models to the real-world implementations?

Positive analogy: Properties known to be similar

Should support transfer of conclusions about the model to conclusions about the target

Negative analogy: Properties known to be different

Should block the transfer of some conclusions


Knowledge questions
Prior beliefs:
• Theories
• Specifications
• Experiences
• Lessons learned
Empirical research
Posterior beliefs:
Updated
• Theories,
• Specifications,
• Etc.

Kinds of empirical research methods

	Experimental study (treatment)	Observational study (no treatment)
Sample-based: investigate samples drawn from a population, look at averages and variation, infer population parameters	• **Statistical difference-making experiment**	Survey
Case-based: investigate cases one by one, observe case architecture and at interaction mechanisms among components	• **Expert opinion (e.g. a focus group, or individual interviews),** • **Case-based experiments (e.g. a simulation / game, pilot project),** • **Technical action research**	Observational case study

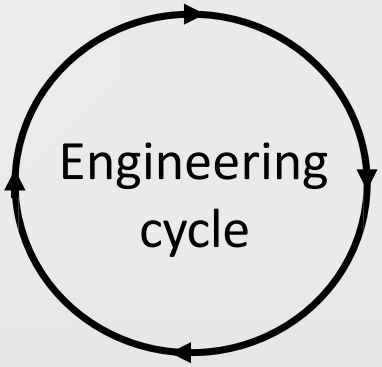
- The methods in **bold** are useful for validation research

Engineering cycle

Legend:
? Knowledge questions
! Tasks

Design implementation

Choose a treatment!
Transfer to practice!



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Engineering cycle

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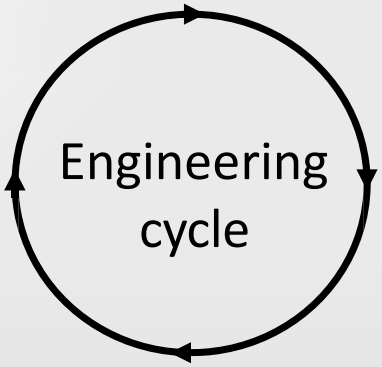

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The empirical research cycle

This is the rational decision cycle applied to answer knowledge questions (empirical research questions)

- Research Problem analysis
- Research and inference design
- Validation (pilot)
- Research execution
- Data analysis

The research context

1. Knowledge goal(s)
– What do you want to know? Is this part of an implementation evaluation, a problem investigation, a survey of existing treatments, or a new technology validation?

2. Improvement goal(s)?
– If there is a higher-level engineering cycle, what is the goal of that cycle?
– If this is a curiosity-driven project, are there credible application scenarios for the project results?

3. Current knowledge
– State of the knowledge in published scientific, technical, and professional literature?
– Available expert knowledge?
– Why is your research needed? Do you want to add anything, e.g., confirm or falsify something?
– Theoretical framework that you will use?

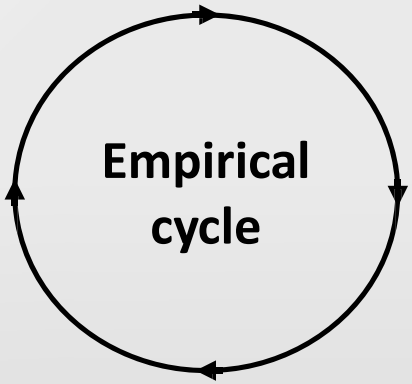
New research problem

Data analysis

12. Data?
13. Observations?
14. Explanations?
15. Generalizations?
16. Answers?

Research execution

11. What happened?



Research problem analysis

4. Conceptual framework?
5. Research questions?
6. Population?

Validation

7. Object of study justification?
8. Treatment specification justification?
9. Measurement specification justification?
10. Inference justification?

Research design

7. Object of study?
8. Treatment specification?
9. Measurement specification?
10. Inference?