# Design Science Methodology Minitutorial

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# Outline

- Design science
  - Research problems
- Design theories
  - Design research methods

- R.J. Wieringa. *Design Science Methodology for Information Systems and Software Engineering*. Springer, 2014.
- Slides and other material at http://wwwhome.ewi.utwente.nl/~roelw/

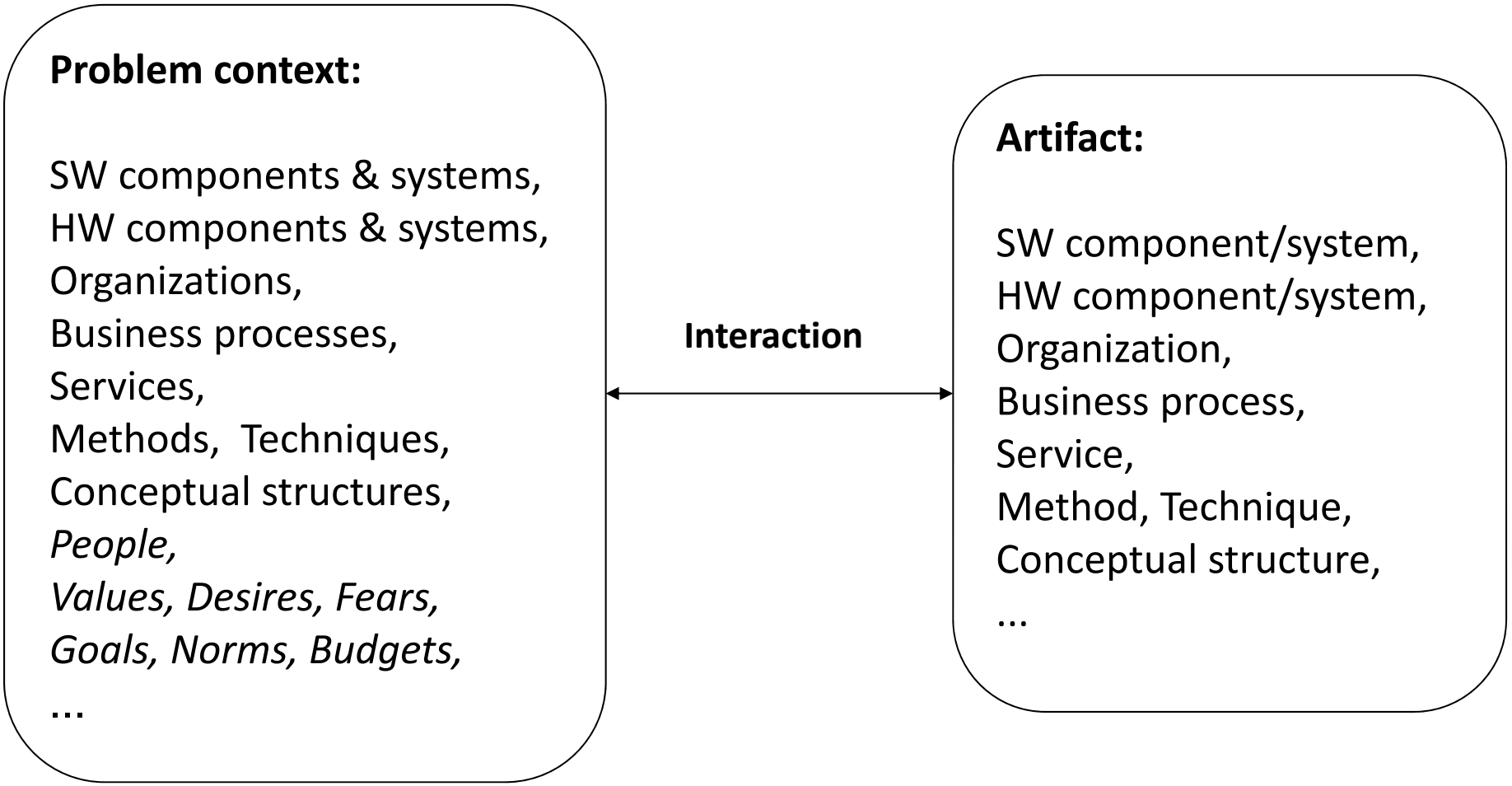
# Outline

- **Design science**
  - Research problems
- Design theories
  - Design research methods

- Design science is the design and investigation of artifacts in context

- Design science is the design and investigation of **artifacts in context**

# Subjects of design science

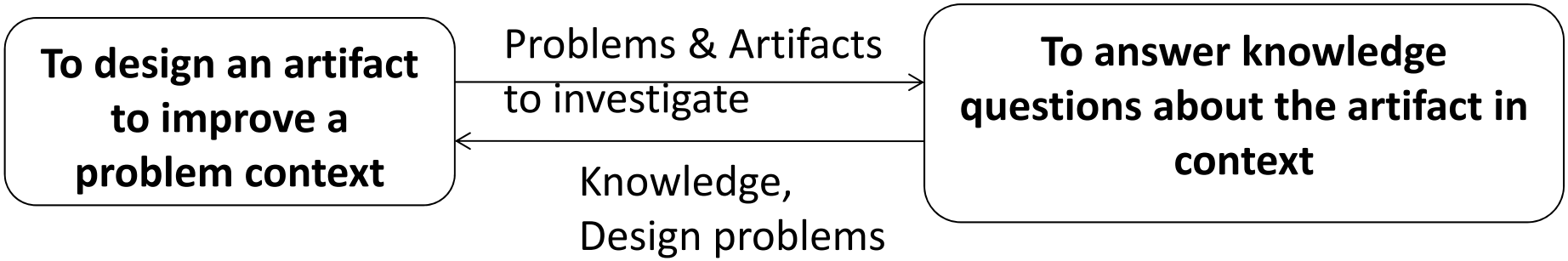



Something to be influenced

Something to be designed

- Design science is the **design and investigation** of artifacts in context

# Research problems in design science

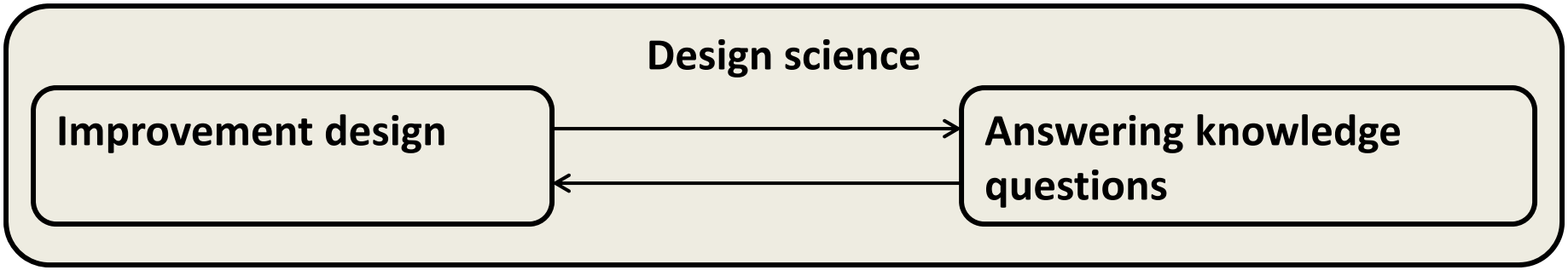



- *"Design a DoA estimation system for satellite TV reception in a car."*
- *"Design a multi-agent aircraft taxi-route planning system for use on airports"*
- *"Design an assurance method for data location compliance for CSPs"*

- *"Is the DoA estimation accurate enough?"*
- *"Is this agent routing algorithm deadlock-free?"*
- *"Is the method usable and useful for cloud service providers?*

The design researcher iterates over these two activities

# The context of design research



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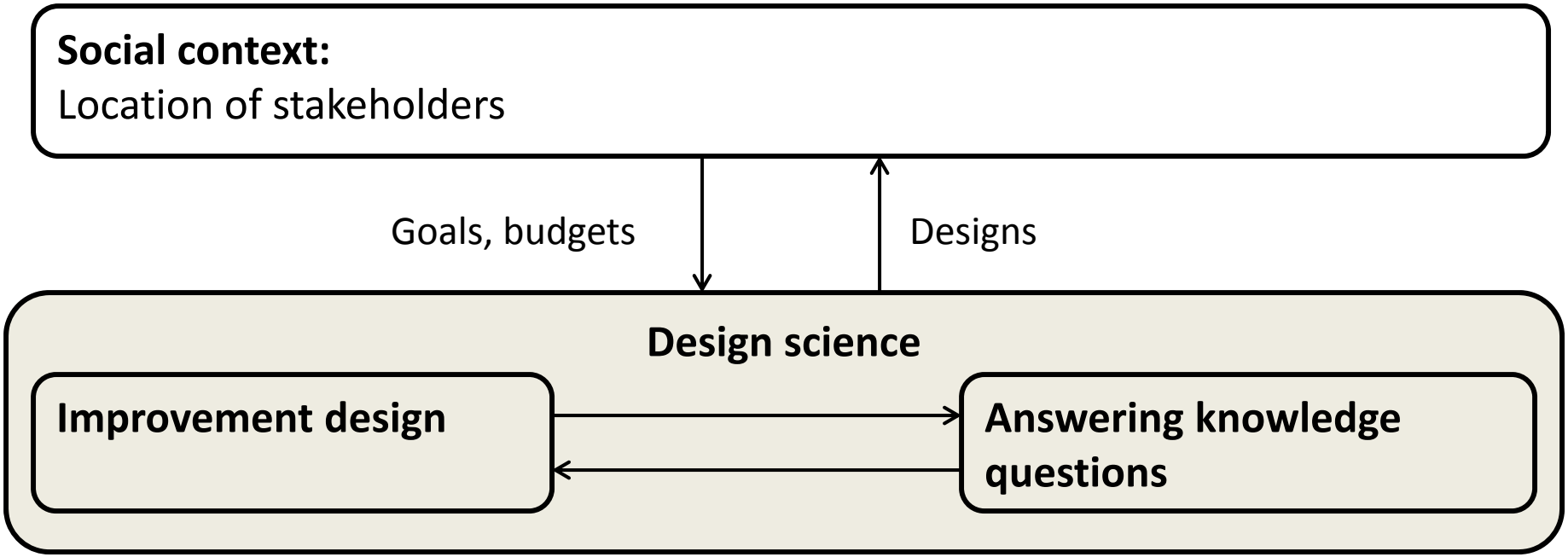

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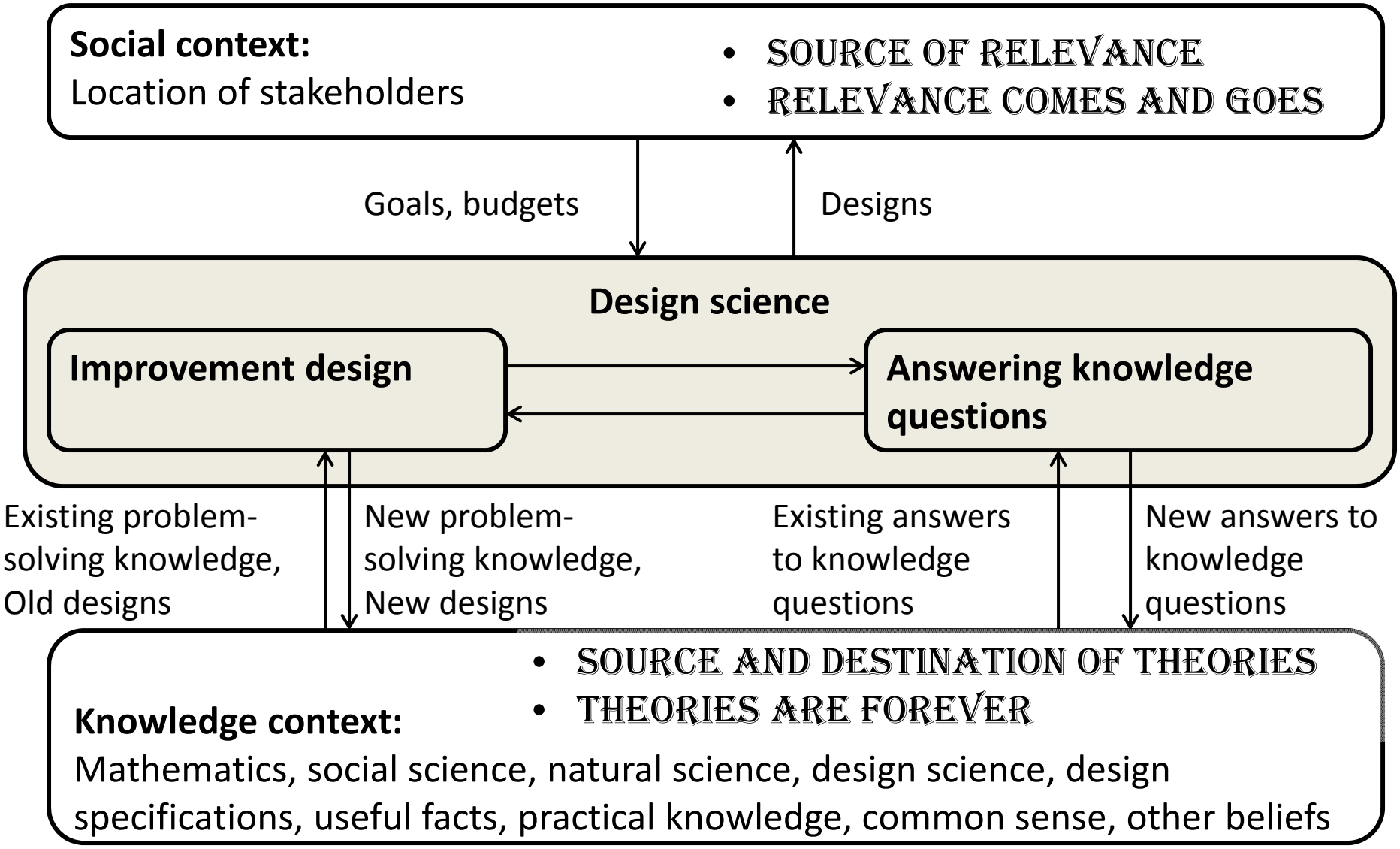

# Outline

- Design science
  - **Research problems**
- Design theories
  - Design research methods

# Two kinds of research problems

- Design problems
- Knowledge questions

# Template for design problems

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

- *Reduce my headache*
- *by taking a medicine*
- *that reduces pain fast and is safe*
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Stakeholder language:
**Problem context and stakeholder goals.**

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Technical language:
**Artifact and its desired properties.**

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- *Improve the course admin*
- *By integrating with student admin*
- *Such that less data need be entered*
- *In order to reduce workload*

- Design problems are usually not considered to be research problems
- They are stated in the form of questions
  - *How to plan aircraft taxi routes dynamically?*
  - *Is it possible to plan aircraft routes dynamically?*
  - *Etc.*
- This way, stakeholders, goals, and requirements stay out of the picture!

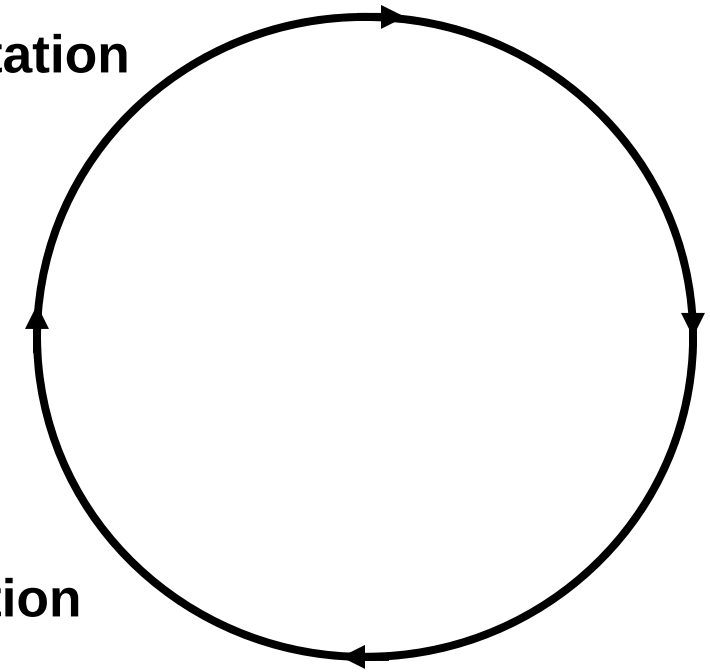
Legend: Knowledge questions? Actions!

# Engineering cycle (a.k.a. regulative cycle)

**Design implementation**

**Implementation evaluation = Problem investigation**

- Stakeholders? Goals?
- Conceptual problem framework?
- Phenomena? Causes? Effects?
- Effects contribute to Goals?



**Design validation**

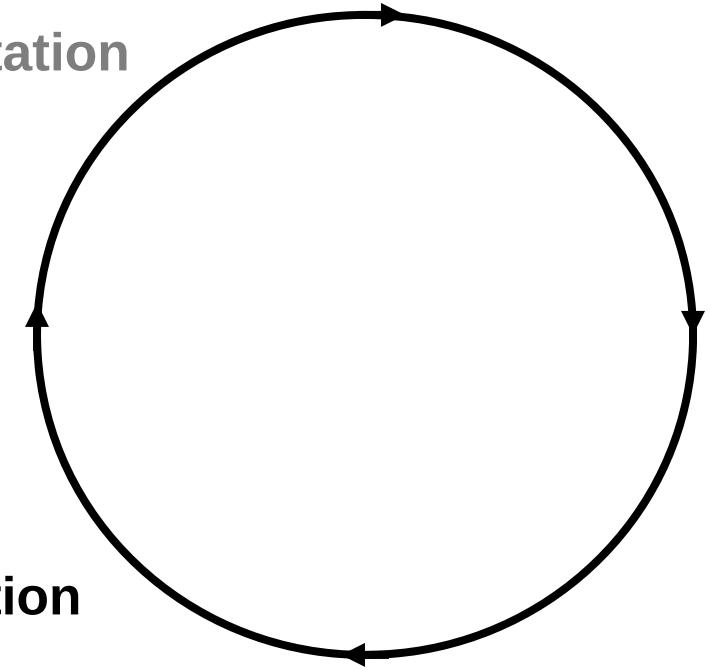
- Context & Artifact → Effects?
- Effects satisfy Requirements?
- Trade-offs for different artifacts?
- Sensitivity for different Contexts?

**Treatment design**

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

# Implementation (transfer to problem context) is not part of research

**Design implementation**



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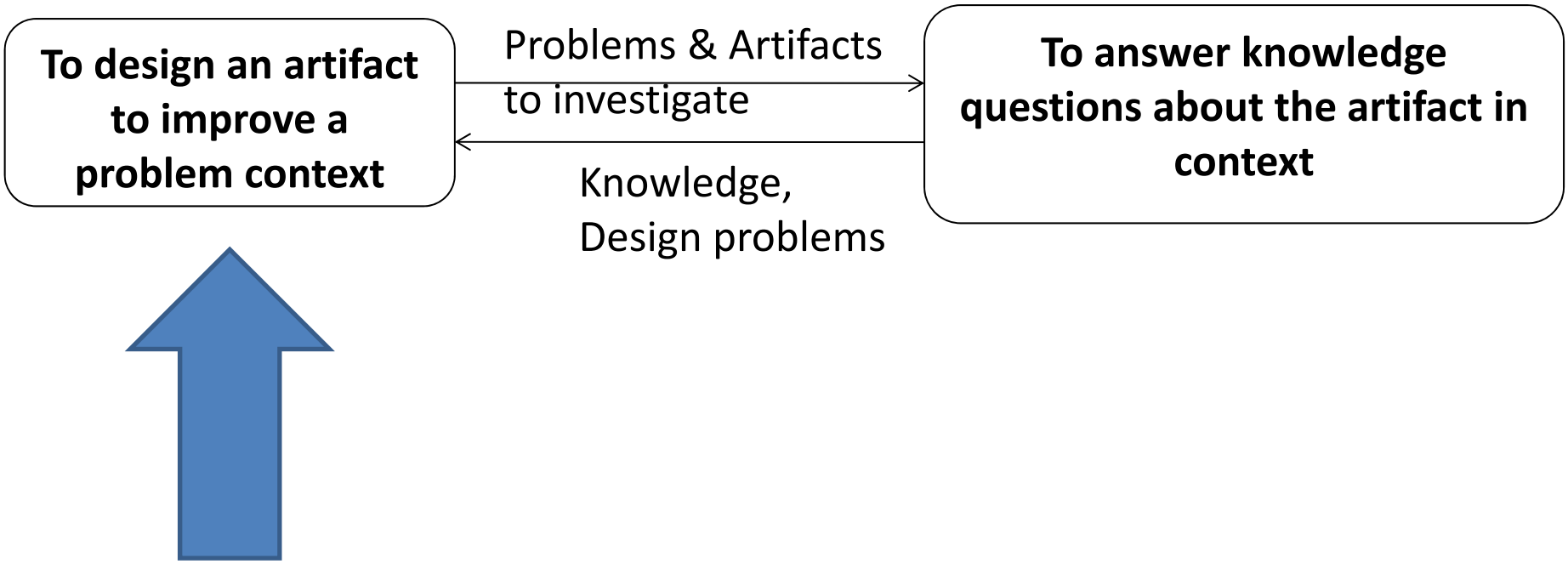
- Research projects may focus on
  - Implementation evaluation
  - Problem investigation
  - Treatment design and validation

# Research problems in design science



# Knowledge questions

- Descriptive questions:
  - What happened?
  - When?
  - Where?
  - What components were involved?
  - Who was involved?
  - etc.
- Explanatory questions:
  - Why?
    - What has **caused** the phenomena?
    - Which **mechanisms** produced the phenomena?
    - For what **reasons** did people or organizations do this?

Journalistic questions.
Yield facts.

Beyond the facts.

- *Descriptive question: What is the performance of this program?*
  - *Execution time for different classes of inputs*
  - *Memory usage*
  - *Accuarcy,*
  - *Etc. etc.*
- *Explanatory question: Why does this program have this performance?*
  1. *Cause: because it received this input (and not anothyer input)*
  2. *Mechanism: because it has this architecture with these components*
  3. *Reasons: Because users use it for tasks  for which it was not intended*

# Effect questions

- Central effect question
  - **Effect question:** Context X Artifact → Effects?
- Generalizations
  - **Trade-off question:** Context X ***Alternative artifact*** → Effects?
  - **Sensitivity question:** ***Other context*** X artifact → Effects?

# Contribution questions

- Preliminary questions:
  - **Stakeholder question:** Who are the stakeholders?
  - **Goal question:** What are their goals?
- Central contribution question:
  - **Contribution question:** Do Effects contribute to Stakeholder goals?

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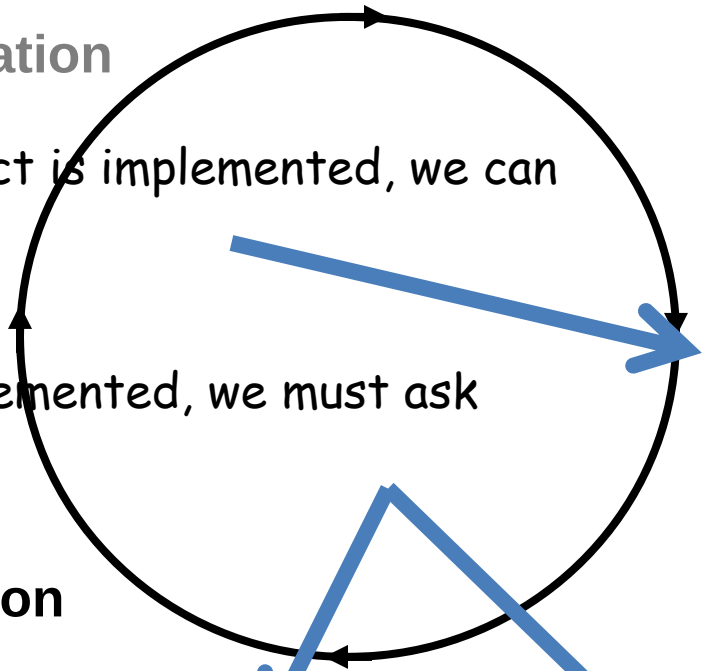


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# Example knowledge questions

- ***Effect:***
  - *What is the execution time of the DoA algorithm?*
  - *What is its accuracy?*
- ***Trade-off:***
  - *Comparison between algorithms on these two variables*
  - *Comparison between versions of one algorithm*
- ***Sensitivity:***
  - *Assumptions about car speed?*
  - *Assumptions about processor?*
- ***Stakeholders:***
  - *Who are affected by the DoA algorithm?*
- ***Goals:***
  - *What are their goals?*
- ***Contribution evaluation (after DOA algorithm is in use)***
  - *How well does the DoA algorithm contribute to these goals?*

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  - Research problems
- **Design theories**
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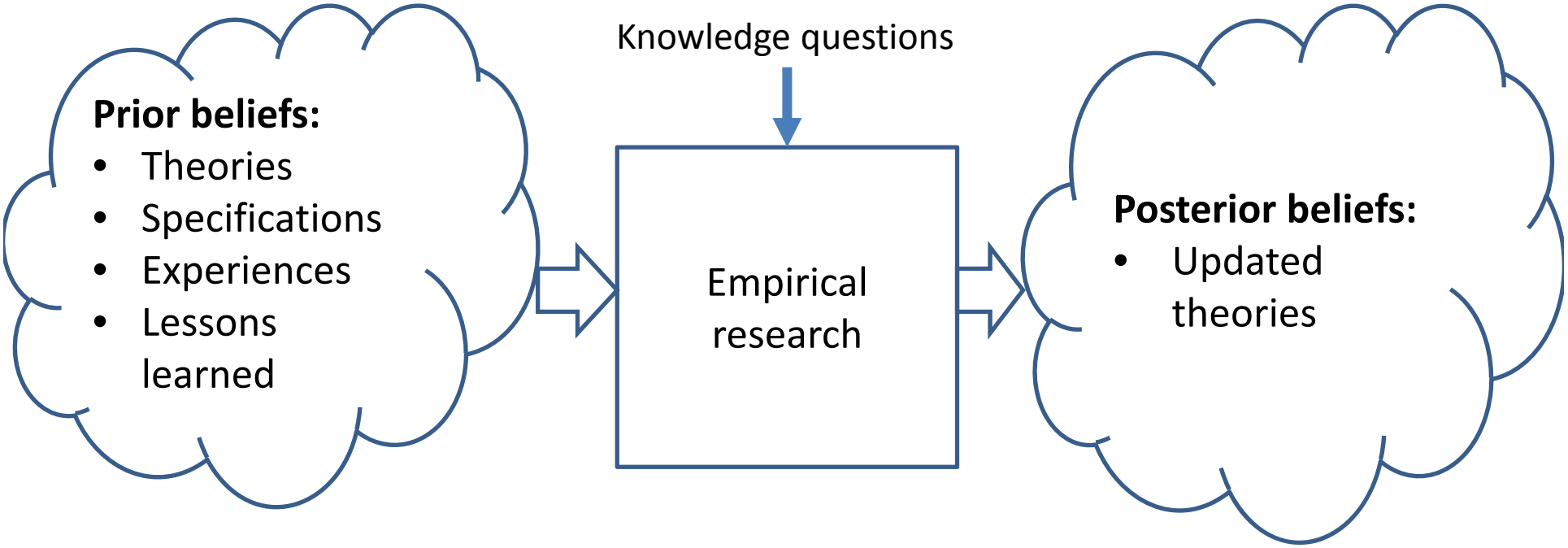
# Empirical research




- The goal of empirical research is to develop, test or refine theories

- A **theory** is a belief that there is a pattern in phenomena
  - Speculations
  - Opinions
  - Ideologies
  - …
- A **scientific** theory is a theory that
  - Has survived tests against experience
  - Has survived criticism by critical peers
- All theories about the real world are fallible

# The structure of scientific theories

1. **Conceptual framework**
   - Constructs to frame, describe, specify, analyze, generalize about phenomena
   - Descriptions can be case-based or sample-based
2. **Generalizations** about patterns in phenomena
   - Statements that explain phenomena.
   - Explanations can be causal, architectural, or rational
   - Scope.

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2. **Generalizations** about patterns in phenomena
   - Statements that explain ***interactions between artifact and context*.**
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# The functions of scientific theories

- To **analyze** a conceptual structure
- To **describe** phenomena (descriptive statistics, interpretation)
- To **explain** phenomena
- To **predict** phenomena (analytical or statistical generalizations of a theory, or use models)
- To **design** an artifact by which to treat a problem

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# Statistical theories

- Conceptual framework:
  - Population, variables, distributions
  - Nondeterminism represented by probability distributions
- Descriptipons are statistical
  - E.g. “one iteration of the main loop takes less that 7.2 ms.”
  - E.g. “Variation in X explains $R^2$ of the variation in Y”. This is really a statistical description.
- Explanations may be causal
  - If X causes Y, then on the average, a change in X results in a change in Y (difference-making).

# History of statistical conceptual structures

- Statistical conceptual frameworks are used in
  - Social sciences: human populations
  - Physics: statistical mechanics
  - Biology: populations of animals, plants
  - Psychology: groups of people
  - Information systems: populations of organizations
  - Empirical software engineering: populations of projects, software engineers

1800
- Population-based statistics (descriptive, including regression)

1900
- Sample-based statistics (statistical inference)

2000
- Very large sample (population)-based statistics

- To average out competing causes, causal explanations require statistical research.

- In the field, the causal influence of X on Y may be swamped by many other causal influences.
  - Lab research versus field research

# Architectural theories

- Conceptual framework
  - Components, capabilities, interactions among components
- Explanations are architectural
  - Phenomenon Y occurred because components C1, …, Cn interacted in this way (technical, social, psychological, biological mechanism)
  - Rational explanations: Actor A did this because A had this goal
- Examples:
  - *DOA architectural theory: e.g. input-output relation is explained by structure of the algorithm*
  - *In agile development for SME, the SME does not put customer on-site. SME resources are limited (capability) and focus is on business (goal).*
  - *Introduction of change control board reduces requirements creep.*

# History of architectural conceptual structures

- This kind of structure is used in
  - The engineering disciplines: Renaissance machines
  - Astronomy: architecture of solar system; math descriptipon
  - Physics: forces among physical bodies
  - Biology: structure and mechanisms in the body
  - Chemistry: composition and mechanisms of compustion
  - Sociology: structure and mechanisms of of society, organizations,
  - Psychology: cognitive mechanisms
  - Economy: structure and mechanisms of markets
  - Sociology, economy, computer science, Structure & mechanisms of networks and games

1500

1600

1800

1900

2000

- Architectural explanations are appropriate in case-based research

- In the field, different mechanisms may interfere, to give unpredictable result (but explainable in individual cases).
  - Lab research (prototyping, simulation, gaming) versus field research (real-world case studies)

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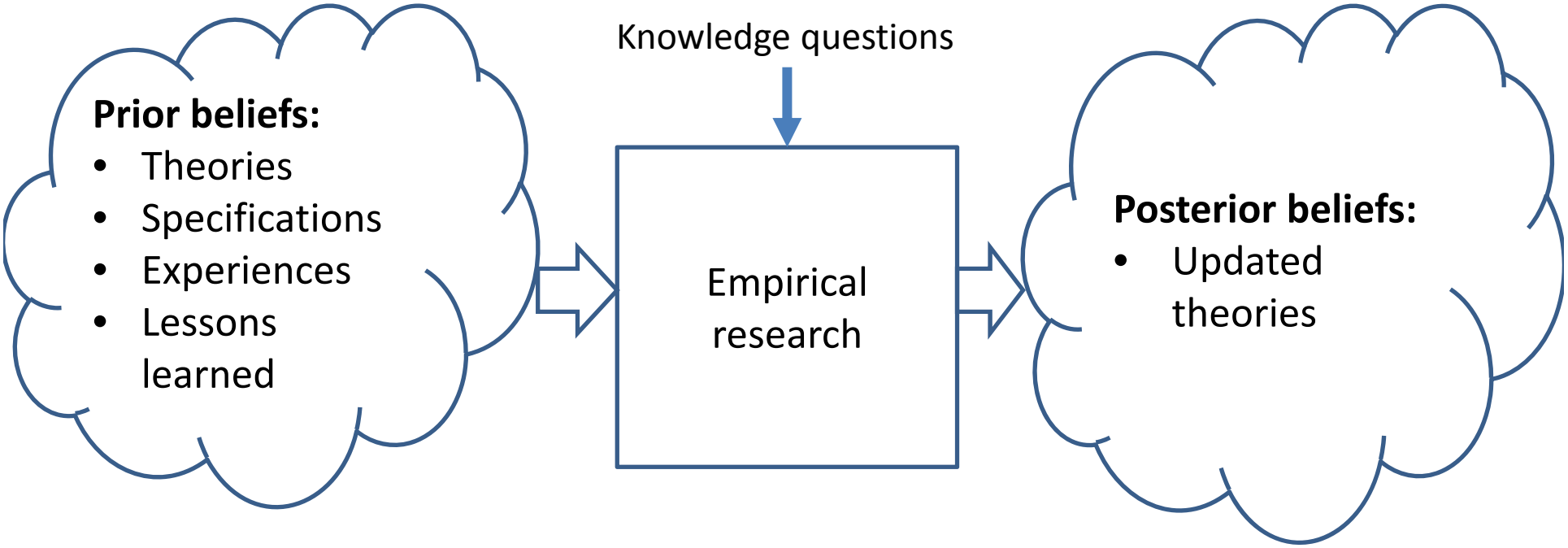
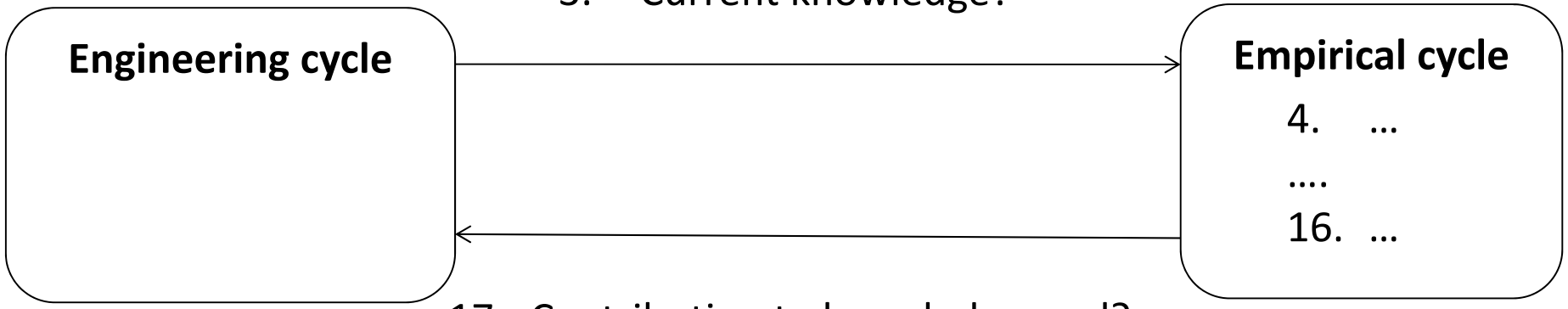
# Empirical research




- The goal of empirical research is to develop, test or refine theories

# Checklist questions about research context

1. Improvement goal?
2. Knowledge goal?
3. Current knowledge?




17. Contribution to knowledge goal?
18. Contribution to improvement goal?

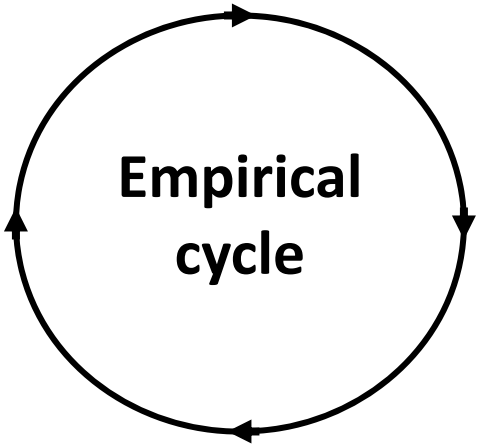
**Data analysis**

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

New research problem

**Research execution**

11. What happened?




**Research problem analysis**

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

Source of rigor

**Design justification**

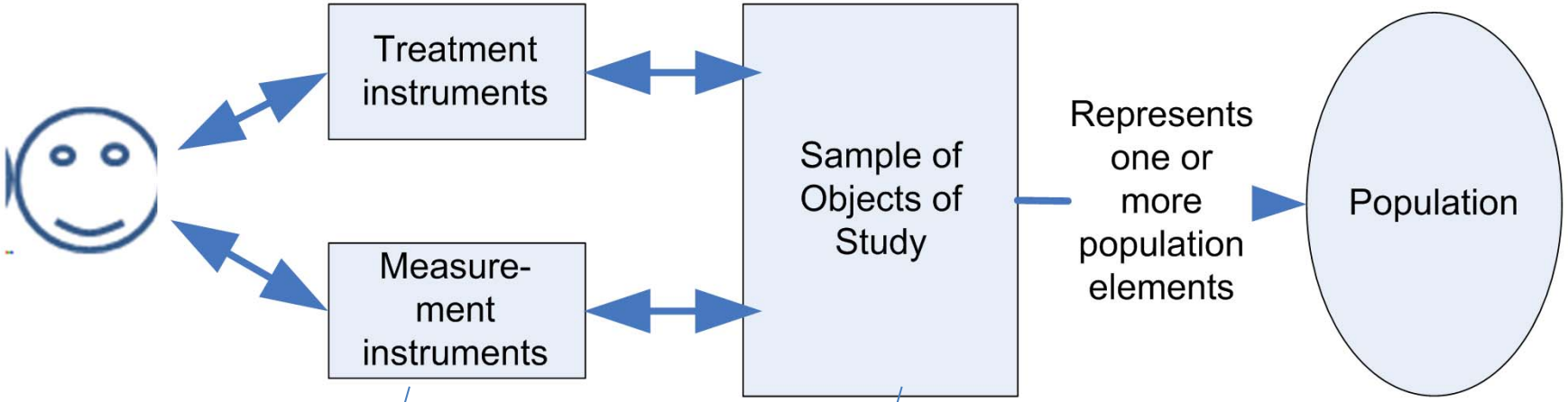
7. Object of study justification?
8. Treatment specification justification?
9. Measurement specification justification?
10. Inference justification?

**Research & inference design**

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

# The empirical research setup

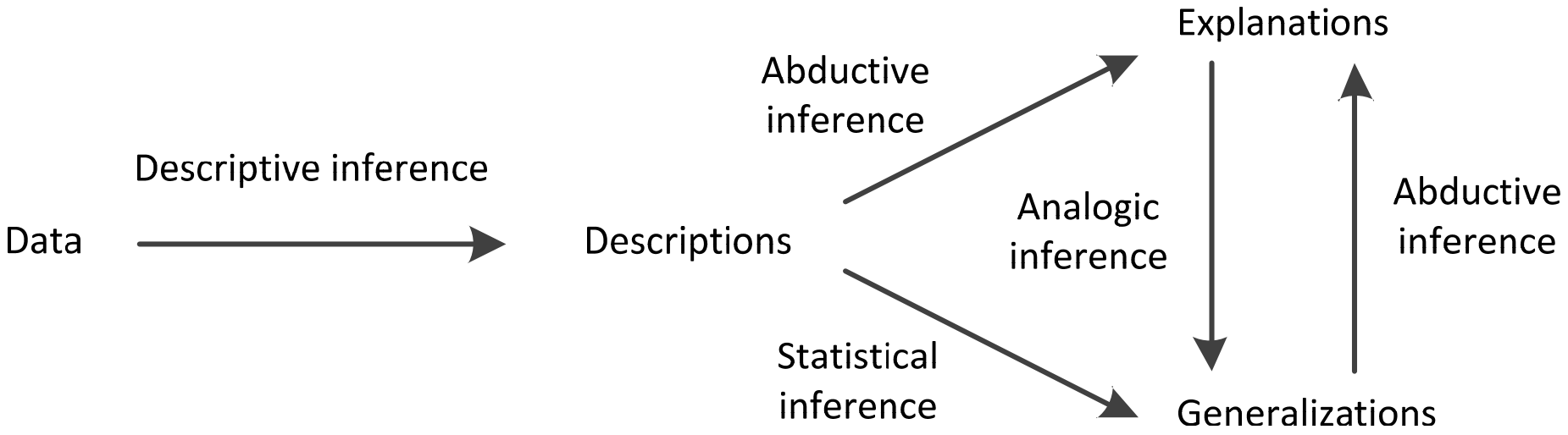
Natural scenario,
artificial scenario, …




Interviews,
Questionnaires,
Software probes,
Sensors,
Cameras,
Clocks,
Participant observation,
…

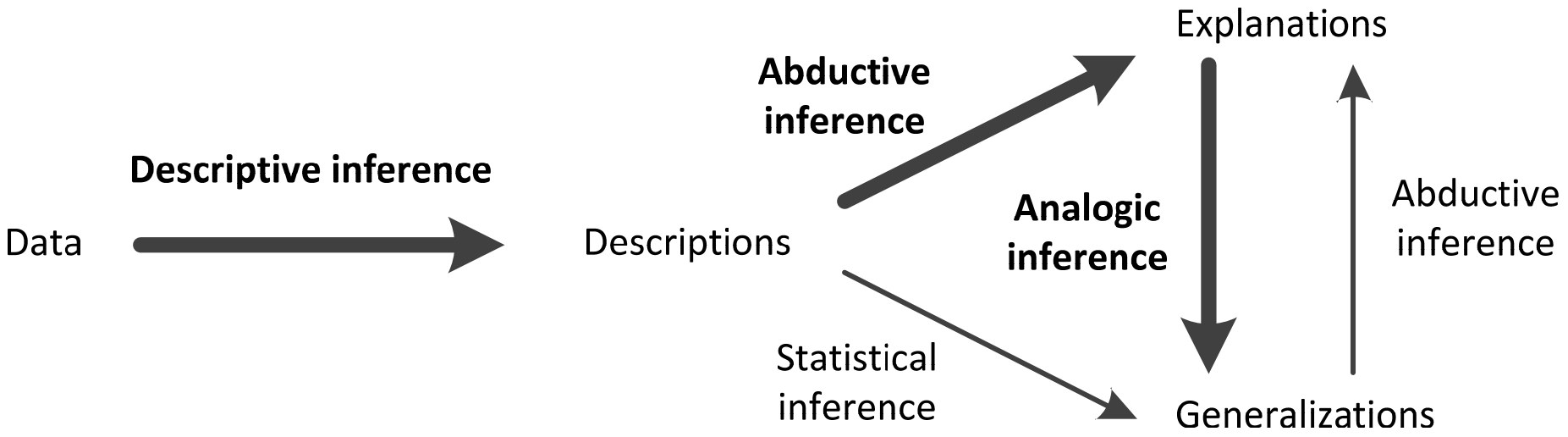
Natural model,
population element,
artificial model,
…

# Four kinds of inference




- All inferences are fallible. **Validity** is degree of support for the inference.

# Case-based inference



# Case-based inference

1. **Descriptive inference:** Describe the case observations.
   - *In a study of a global SE project, describe the organizarional structure and communication & coordination processes based on data obtained from project documents, interviews, email and chat logs.*
   - Discuss **descriptive validity**.

2. **Abductive inference:** Explain the observations architecturally and/or rationally.
   - *Explain reduction of rework by the capabilities of the cross-functional team in the project.*
   - Discuss **internal validity.**

3. **Analogic inference:** Assess whether the explanations would be true of architecturally similar cases too.
   - *Reason that similar teams will produce similar effects, other things being equal.*
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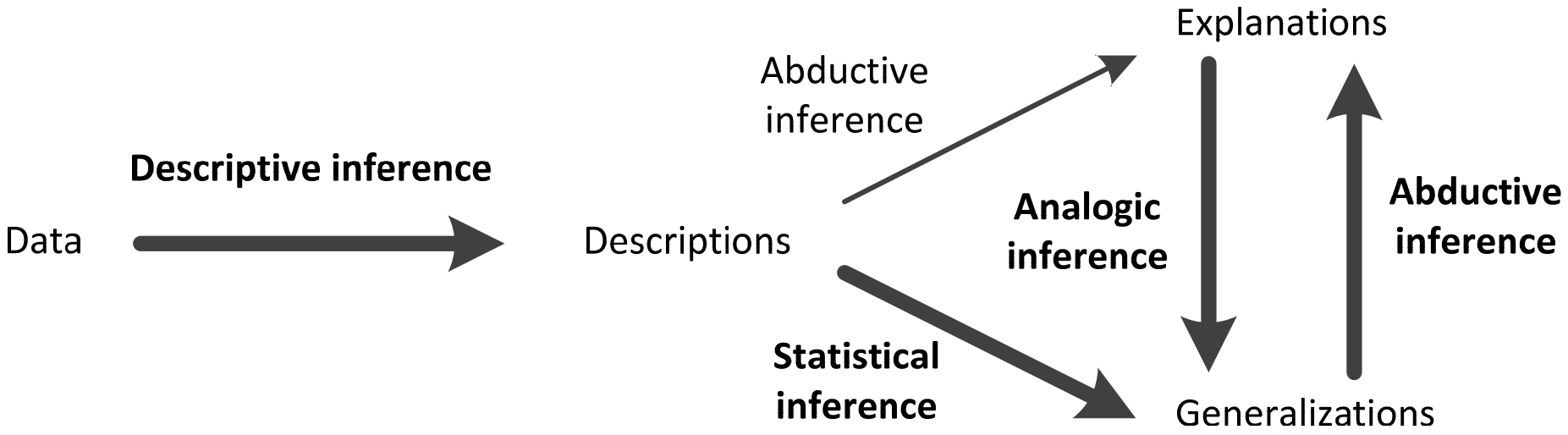
# Case-based reasoning should be architectural

- Architecture gives a better basis for generalization by analogy than variables

# Sample-based inference



# Sample-based inference

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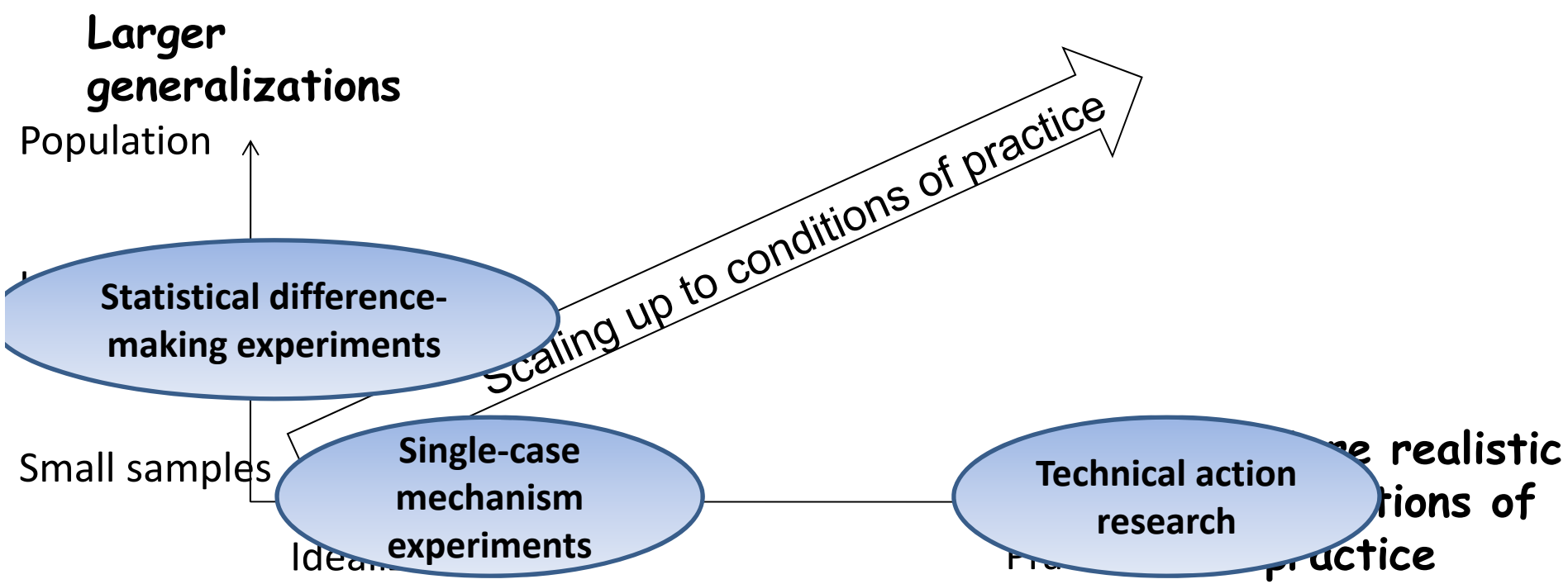
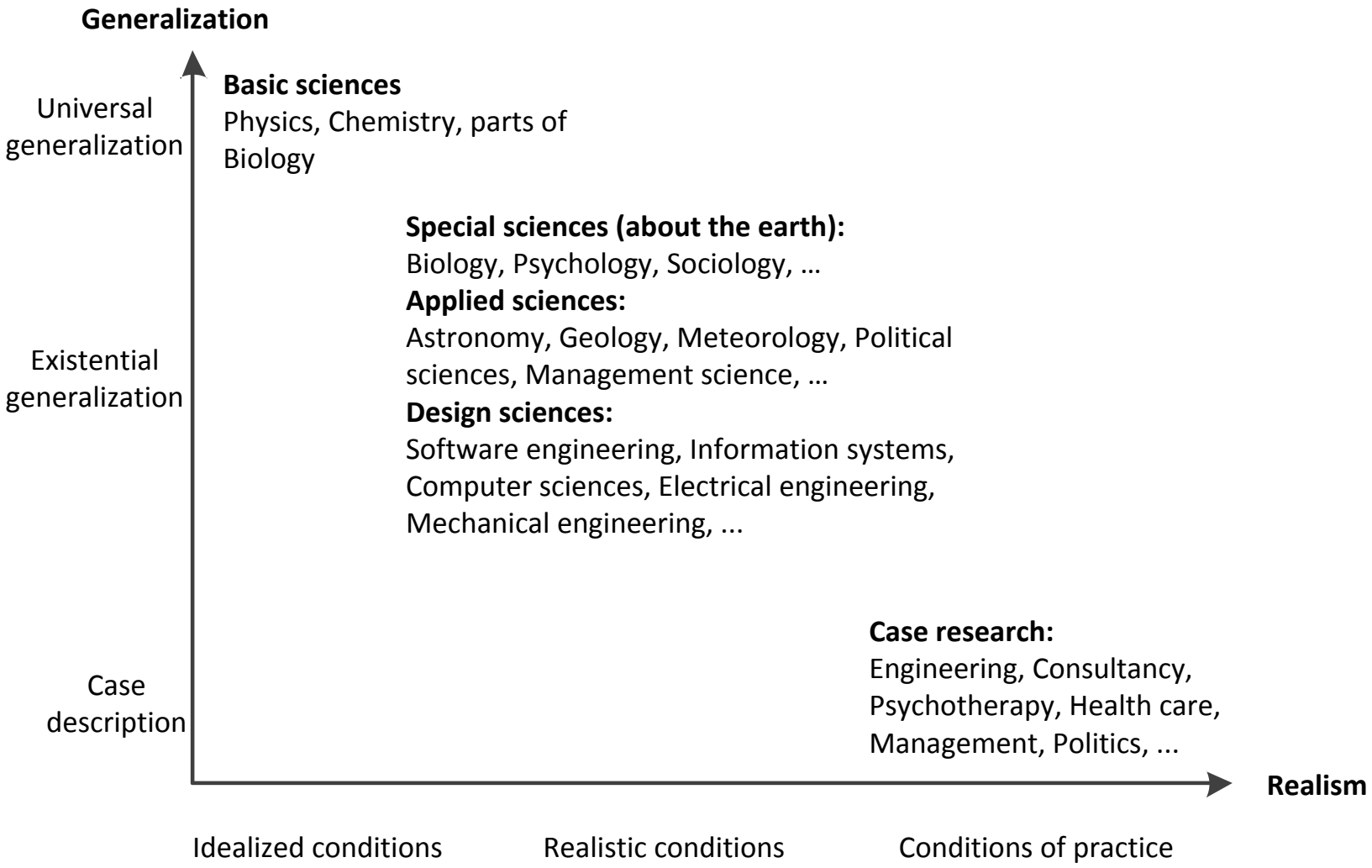
| | Case-based inference | Sample-based inference |
|---|---|---|
| No treatment (observational study) | Observational case study | Survey |
| Treatment (experimental study) | Single-case mechanism experiment, Technical action research | Statistical difference-making experiment |




- If all population elements were identical, statistical inference would not be needed

# Sciences of the middle range



# Take-home

- Design science
  - Design problems and knowledge questions
- Design theories
  - Effects of artifact in context
- Design research methods
  - Case-based and sample-based research
  - Architectural vs. statistical reasoning
  - Scaling up from lab to practice