SCIENTIFIC RESEARCH METHODOLOGIES AND TECHNIQUES

Unit 2: RESEARCH METHOD

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1. BASE TERMINOLOGY

Terms

Methodology - the **study of the methods** involved in some field, endeavor, or in problem solving

Method - a (systematic ?) codified **series of steps** taken to complete a certain task or to reach a certain objective

Methodology is defined as:
- "the analysis of the principles of methods, rules, and postulates employed by a discipline";
- "the systematic study of methods that are, can be, or have been applied within a discipline"; or
- "a particular procedure or set of procedures."

- a collection of theories, concepts or ideas
- comparative study of different approaches
- critique of the individual methods

**Methodology refers to more than a simple set of methods;
it refers to the rationale and the philosophical assumptions that underlie a particular study.**

In recent years *methodology* has been increasingly used as a pretentious substitute for *method* in scientific and technical contexts [Wikipedia]

Nature of the scientific method

The "scientific method" attempts to minimize the influence of the researchers' bias on the outcome of an experiment.

- ***The researcher may have a preference for one outcome or another, and it is important that this preference does not bias the results or their interpretation.***
- ***Sometimes "common sense" and "logic" tempt us into believing that no test is needed.***
- ***Another common mistake is to ignore or rule out data which do not support the hypothesis.***

http://teacher.pas.rochester.edu/phy_labs/appendixe/appendixe.html

But there is no single, universal formal "scientific method". There are several variants and each researcher needs to tune the process to the nature of the problem and his / her working methods.

A task for you !

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2. OVERVIEW OF RESEARCH METHODS

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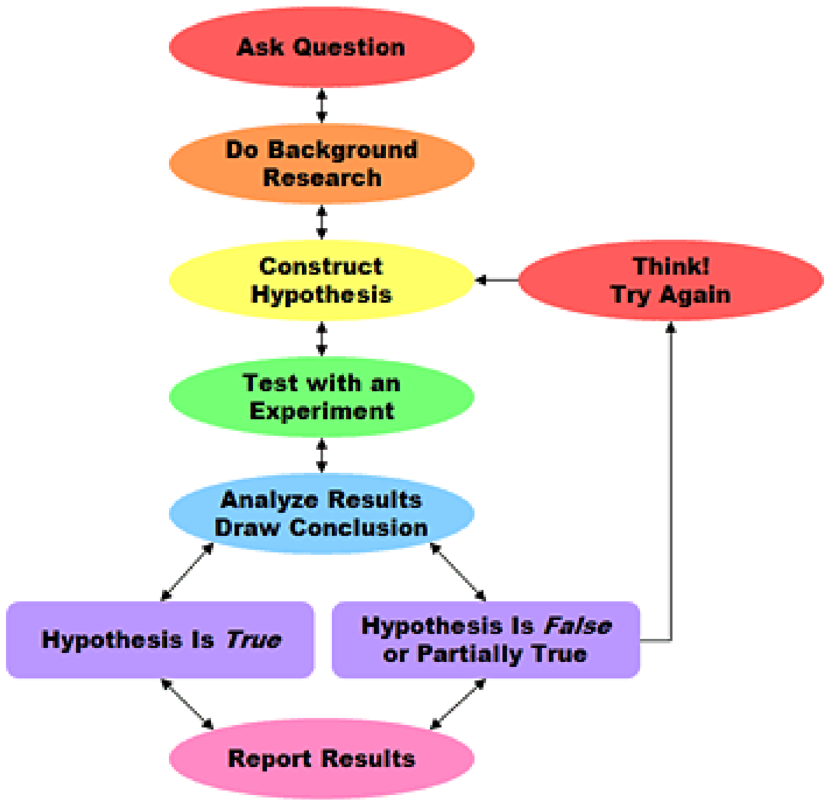
Classical phases

1. Research question / Problem
2. Background / Observation
3. Formulate hypothesis
4. Design experiment
5. Test hypothesis / Collect data
6. Interpret / Analyze results
7. Publish findings

Classical phases ...

1	• Research question / Problem	What are you interested in? What do you have to know about it?
2	• Background / Observation	Make observations & gather background information about the problem.
3	• Formulate hypothesis	An *educated guess* … It shall be possible to measure / test it. It should help answer the original question.
4	• Design experiment	How will you test your hypothesis? What tests will answer your question?
5	• Test hypothesis / Collect data	Test your hypothesis by executing your experiments. Collect data from them.
6	• Interpret / Analyze results	What do your results tell you? Do they prove or disprove the hypothesis? ... It is OK to be wrong.
7	• Publish findings	Write papers for conferences & journals. Write dissertation.

Other variants

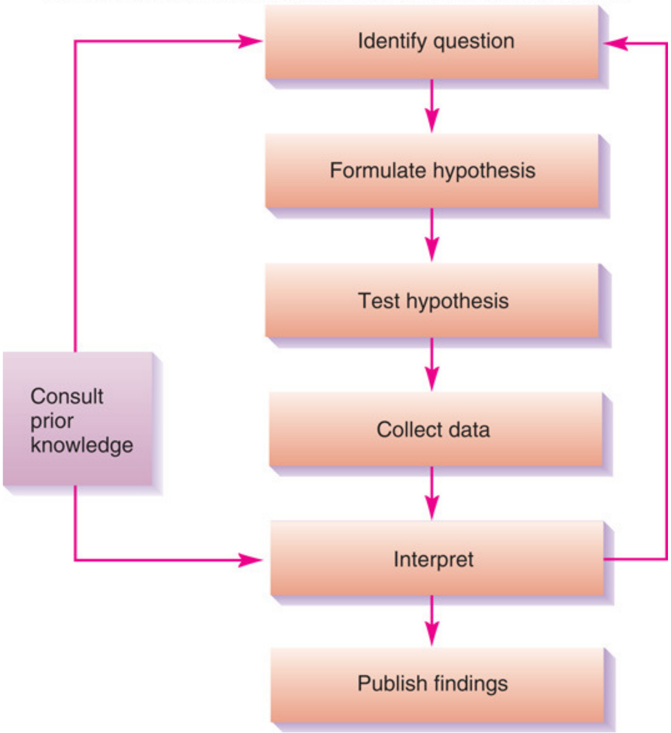


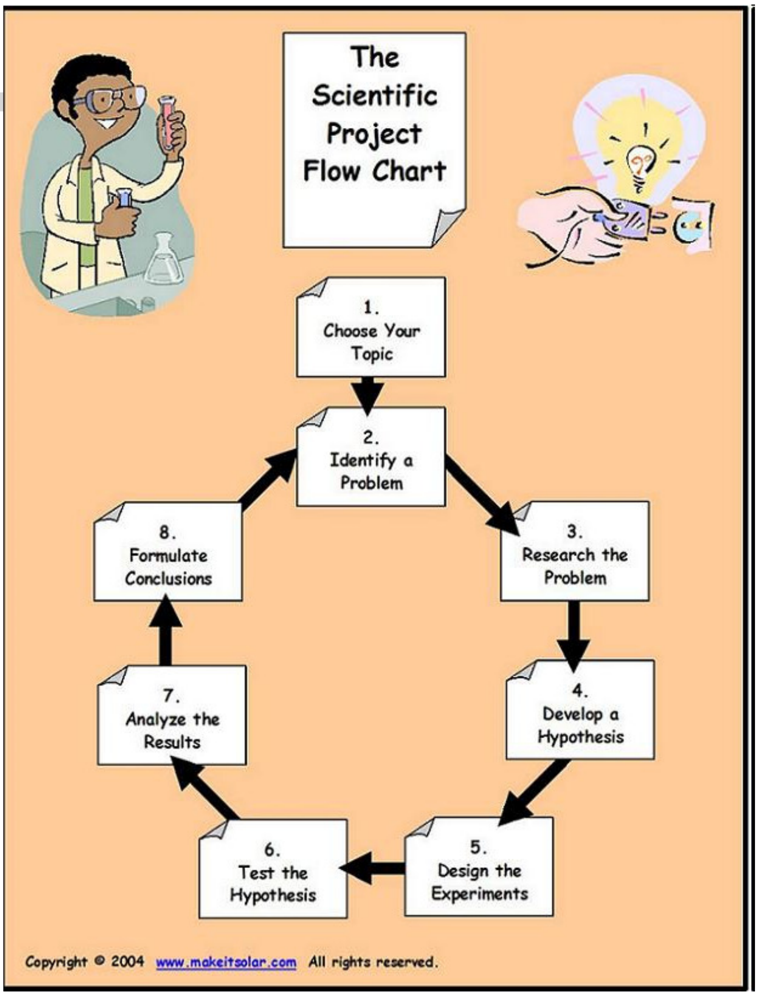
1. Define the question
2. Gather information and resources (observe)
3. Form hypothesis
4. Perform experiment and collect data
5. Analyze data
6. Interpret data and draw conclusions that serve as a starting point for new hypothesis
7. Publish results
8. Retest (frequently done by other scientists)

[Wikipedia]

www.sciencebuddies.org/mentoring/project_scientific_method.shtml

Other variants





www.makeitsolar.com/science-fair-information/01-the-scientific-method.htm

Other variants

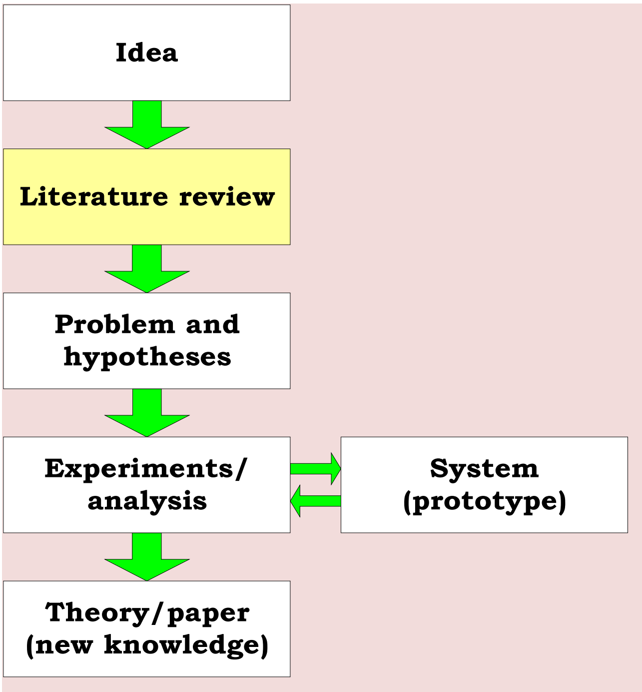
1. **Observe** an event.
2. Develop a **model** (or **hypothesis**) which makes a <u>**prediction**</u>.
3. **Test** the prediction.
4. **Observe** the result.
5. **Revise** the hypothesis.
6. **Repeat** as needed.
7. A <u>successful</u> hypothesis becomes a **Scientific Theory**.

Ask Fred To Act Dramatically Cool

- **A- ask**
- **F- form a hypothesis**
- **T- test hypothesis**
- **A- analyze the results**
- **D- draw conclusions**
- **C- community**

[Nordgren, 2004]

Other variants



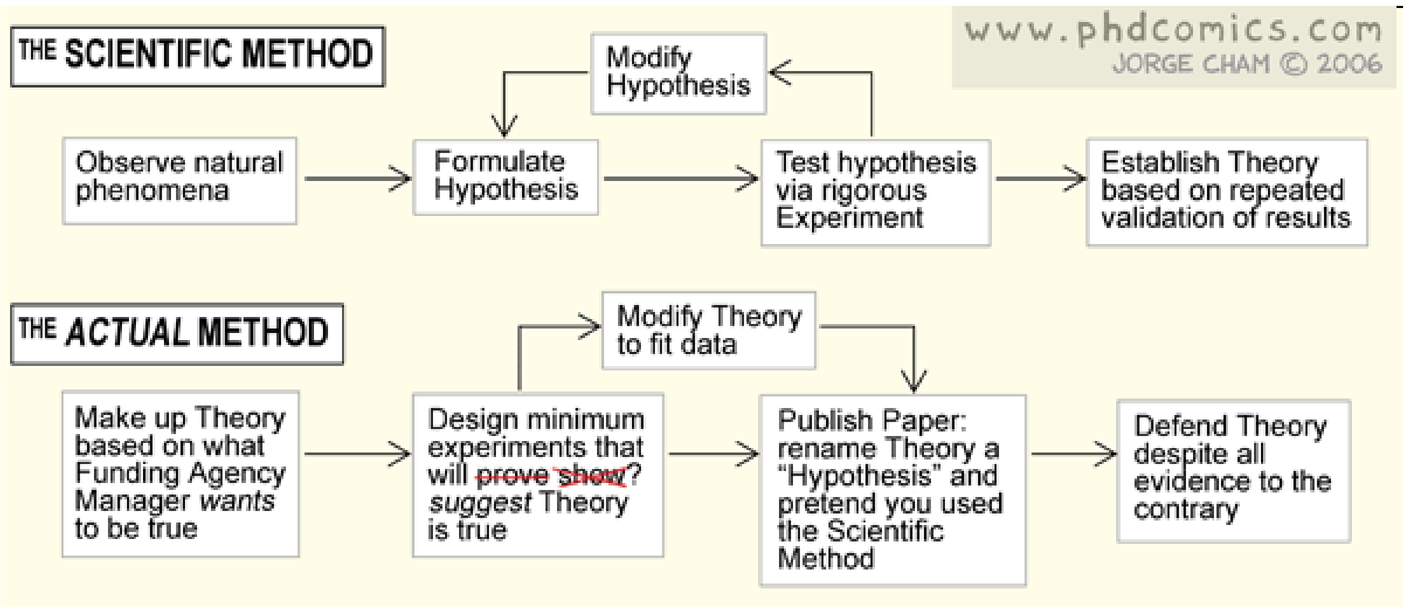
[Mämmelä, 2006]

The Scientific Method Made Easy

YouTube

https://www.youtube.com/watch?v=r_oKpNYRyKc

In practice !



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Errors of experts who did not follow the Scientific Method

Common sense ?

- "Computers in the future may weigh no more than 1.5 tons."
  Popular Mechanics, forecasting the relentless march of science, 1949
- "I think there is a world market for maybe five computers."
  Thomas Watson, chairman of IBM, 1943
- "Airplanes are interesting toys but of no military value."
  Marechal Ferdinand Foch, Professor of Strategy, Ecole Superieure de Guerre.
- "Louis Pasteur's theory of germs is ridiculous fiction".
  Pierre Pachet, Professor of Physiology at Toulouse, 1872
- "Heavier-than-air flying machines are impossible."
  Lord Kelvin, president, Royal Society, 1895.

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3. STEPS OF THE SCIENTIFIC METHOD

Step 1: Formulate Research Question / Problem

- **The most important step in research !**
- **Often comes from the thought:**
  "What we have now is not quite right/good enough – we can do better ..."
- **The research question defines the "area of interest" but it is not a declarative statement.**

  The central research question may be complemented by a few secondary questions to narrow the focus.
- **Research question must be capable of being confirmed or refuted.**
- **The study must be feasible.**

Spending time with your research question formulation is NOT a waste of time!

In search for your research question

Too big a problem? [feasibility issue]

Can I split it ? Which "borders"?

Too small a problem? [trivial issue]

Has it been solved?

Is it relevant ?

Can I "measure" it?

Has it been solved ... but in a not so interesting way?

Which resources ?

Is it clearly formulated ?

Research question / Problem - Examples

EXAMPLE (1 single question)

"Which methods and tools should be developed to make current manufacturing control / supervision systems reusable and swiftly modifiable?"

What could be improved here?

EXAMPLE (multiple questions)

"Q1: What are the main components of logistics costs that determine the logistics and transport network design?

Q2: To what extent are the existing network design and evaluation models sufficient and how can collaboration be incorporated in the network design methodology?

Q3: How can economies of scale and scope, present in the newtork, be taken into account in the network design?

Q4: Is it possible to set boundaries to the development path of the network, and search for a feasible path instead of searching solely for a feasible solution? "

Research question / Problem - Examples

EXAMPLES WITH SOME PROBLEMS:

"The main objective of this work is to contribute to the development of elements of a formal theory for manufacturing systems in order to allow the establishment of a formal methodology for the design and analysis of manufacturing systems"

It states the "idea" ... but it is not formulated as a research question ... and it sounds vague.

"The main research questions which have guided this research work are:
Q1: Which are the main characteristics of a collaborative network and of a collaborative networked environment?
Q2: How can be assessed the performance of a CN?
Q3: Which are the most relevant conceptual frameworks, architectures, reference models, independent and industry-specific initiatives, ICT platforms and their underlying technologies, targeting interoperability in a collaborative networked environment?
Q4: Which are the main requirements for interoperability in a networked environment?
Q5: How can seamless interoperability be achieved?
Q6: Which are the main differences and similarities between existing conceptual frameworks?
Q7: How can conceptual frameworks be compared, and which are the criteria to support such an analysis and evaluation?
Q8: Do the conceptual frameworks and the technological solutions compete or complement each other?
Q9: Which is the path to be followed to allow heterogeneous and geographically distributed organizations to naturally inter-operate?

Too many, no hierarchy, some redundancy.

Very important: Some mistakes

Avoid questions with an infinite (or very large) number of possible answers
You will not be able to find all the answers!
Therefore, try to focus!

Avoid questions that can have as answer "yes" or "no".
This type of questions does not give you the opportunity to answer with a thesis statement!

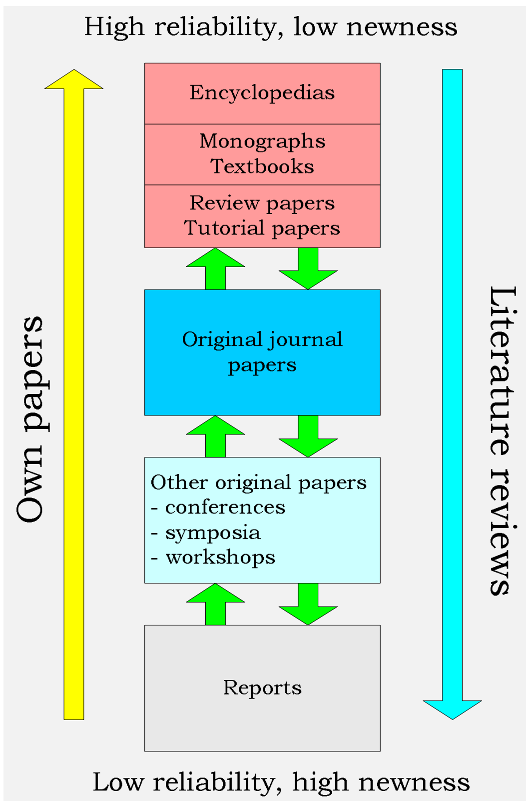
Avoid questions that do not give any hint on how to prove the answer
Try to include some indicators and target values

Do not include a possible answer in the question.
A possible answer can be formulated as a hypothesis.

Step 2: Background / Observation

- **How has the work been done previously? What similar work has been leading up to this point?**
  - Study the state of the art (literature review, projects, informal discussions, etc).
  - Optional realization of preliminary experiments.
- **What distinguishes previous work from what you want to do?**
- **Who / What will be impacted by this research?**

You may iterate between Step 2 and Step 1!



[Mämmelä, 2006]

Step 3: Formulate hypothesis

- A scientific hypothesis states the ‘predicted’ (educated guess) relationship amongst variables.

- Serves to bring clarity, specificity and focus to a research problem
  ... But is not essential
  ... You can conduct valid research without constructing a hypothesis
  ... On the other hand you can construct as many hypothesis as appropriate

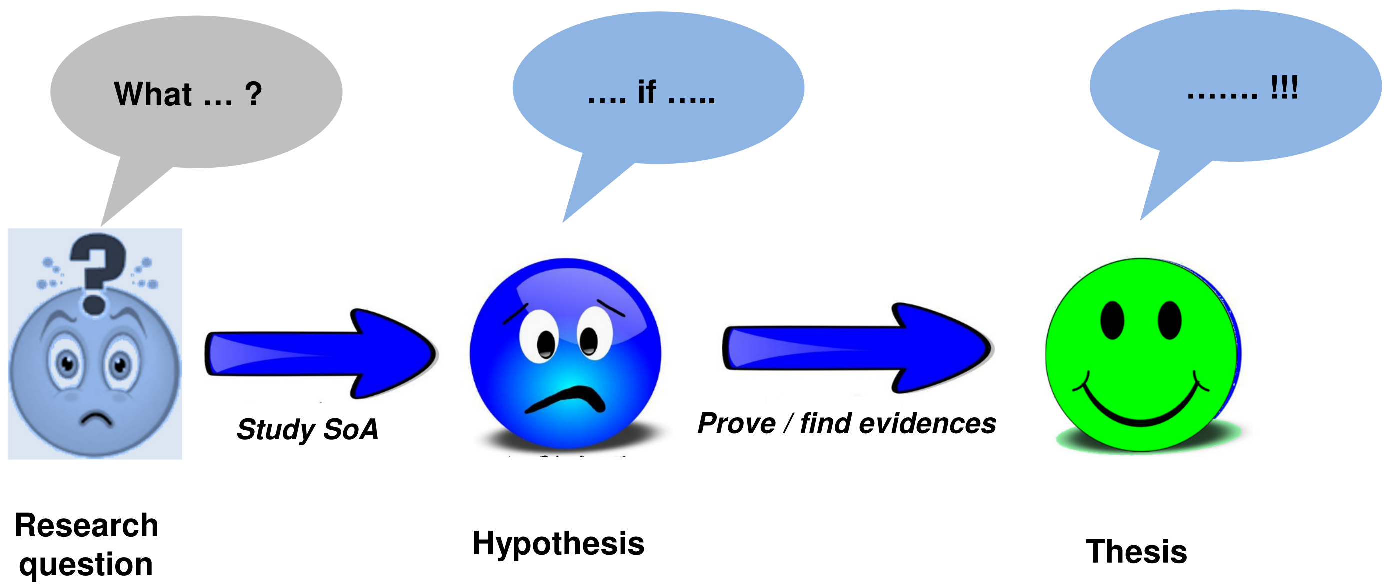
- Stated in declarative form. Brief and up to the point.

- Recommended format (formalized):

  “If ...... then .... (because ....) “ or .... if ....

- In the case of a PhD dissertation, one hypothesis after tested becomes a thesis being defended.
  - One dissertation may include more than one thesis.
  - Sometimes people refer to the dissertation as the “thesis”.

Key steps



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Characteristics of a hypothesis

- **Should be simple, specific and conceptually clear.**
  ... ambiguity would make verification almost impossible.

- **Should be capable of verification.**
  ... i.e. There are methods and techniques for data collection and analysis.

- **Should be related to the existing body of knowledge.**
  ... i.e. Able to add to the existing knowledge.

- **Should be operationalisable**
  ... i.e. Expressed in terms that can be measured.

Remember: A hypothesis is a conditional statement !
…. If …..

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Hypothesis examples

"Shop floor control / supervision reengineering agility can be achieved if manufacturing systems are abstracted as compositions of modularized manufacturing components that can be reused whever necessary, and, whose interactions are specified using configuration rather than reprogramming."

"The process of creating dynamic virtual organizations can become more agile if an appropriate electronic negotiation wizard environment is established with the necessary soft modeling characteristics to structure and conduct the entire negotiation process, making it traceable, reducing the collaboration risks, and managing the participants' expectations."

Often PhD dissertations fail to make explicit their hypothesis / thesis.

Sometimes the reader can hardly "find" them implicit in a section of "contributions" of the dissertation.

Hypothesis – independent & dependent variables

The hypothesis shall contain two types of variables:
Independent Variable(s)
and
Dependent Variable(s)

Dependent Variable - the one you measure or observe.
It's the effect of the researcher's change.

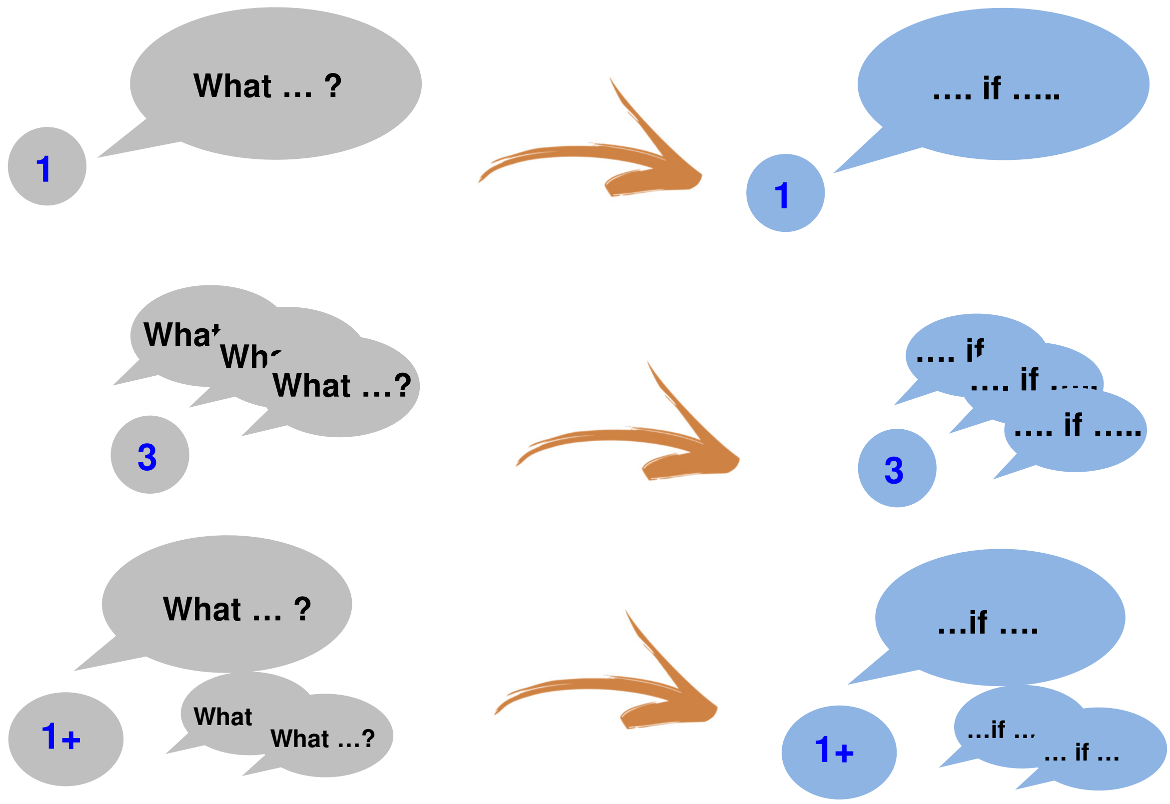
Independent Variable - the one the researcher controls.
It is what you, the researcher, change to cause a certain effect.

"If skin cancer is related to ultraviolet light, then people with a high exposure to UV light will have a higher frequency of skin cancer."

"If temperature affects leaf color change, then exposing the plant to low temperatures will result in changes in leaf color."

Very important

If you have ..... **Then you should have .....**

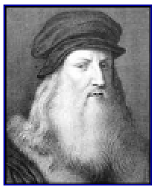


Step 4: Design experiment

- Includes <u>planning in detail</u> all the steps of the experimental phase.
  In engineering research it often includes the design of a prototype / system architecture.
- Identify the variables that will be manipulated and measured – the research outcomes must be measurable.
  In other words:
  What needs to be controlled in order to get an unbiased answer to the research question.
- Therefore: it is necessary to <u>not only</u> design a prototype / system but also plan the thesis validation method !
  How to validate the thesis?
- The plan should allow others to repeat it. It should be feasible...!
- Plan intermediate milestones.

If you fail to plan, you planned to fail !

"All sciences are vain and full of errors that are not born of experience, mother of all certainty, and that are not tested by experience…."

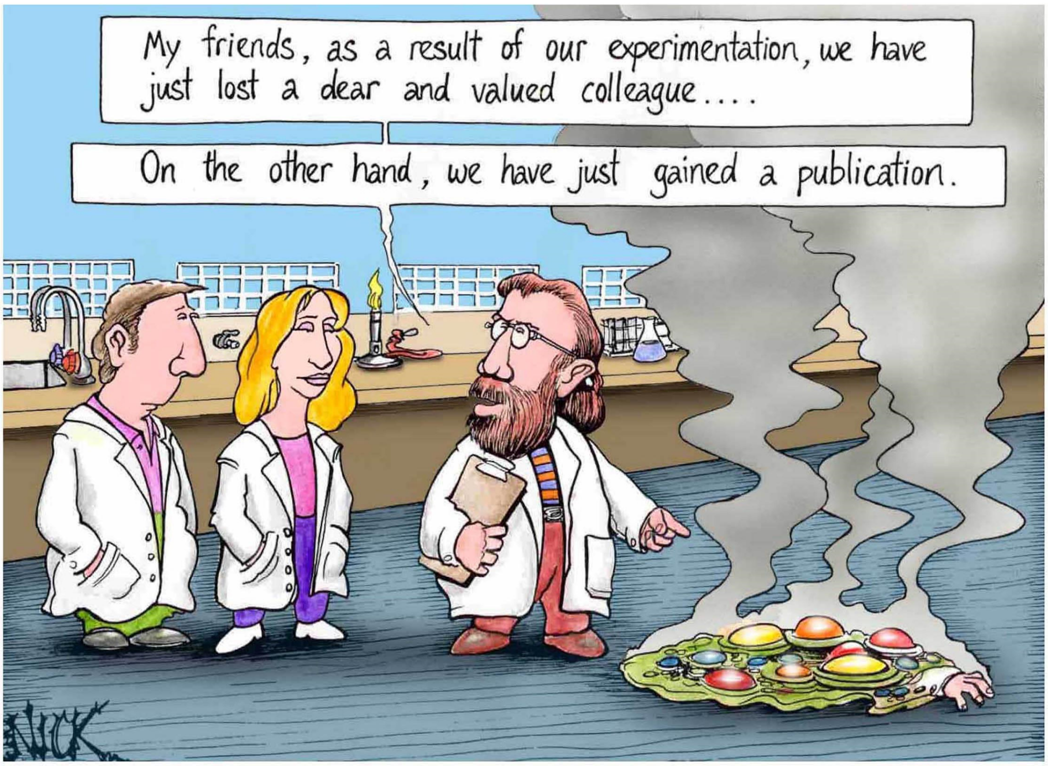


Leonardo da Vinci

Step 5: Test hypothesis / Collect data

- Doing it !
- Implementation of methods (e.g. prototyping) and auxiliary tools (e.g. simulation)
- Pilot testing and refinement.
- Field vs. Laboratory work.
- Any ethical considerations ?
- Confirm results by retesting !

Test hypothesis – perform experiments



Step 6: Interpret / Analyze results

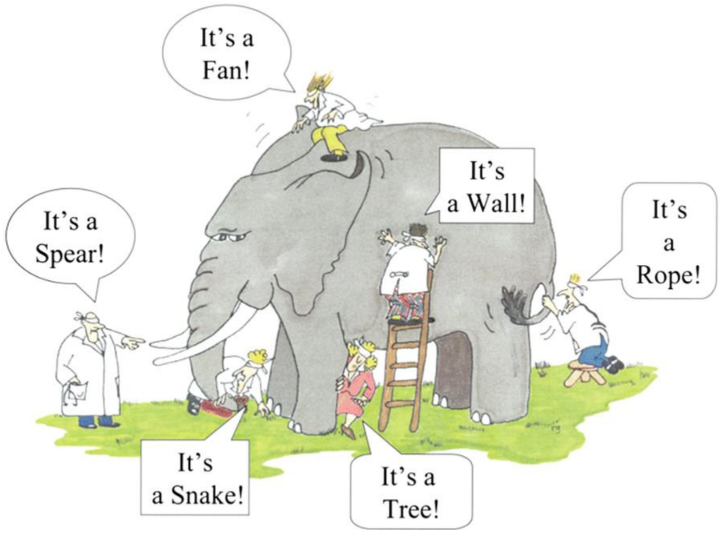
- What did your experiment show?
- Qualitative data analysis.
- Quantitative data analysis.
  - Descriptive and inferential statistics, clustering, ...
- What might weaken your confidence in the results (critical spirit)?
- Discussion regarding
  - Literature
  - Research objectives
  - Research questions.
- Consider next steps
  - Recommendations for further research.

Interpret / Analyze results

Young girl or old lady?

HINT:
Use the girls face as the old woman's nose.

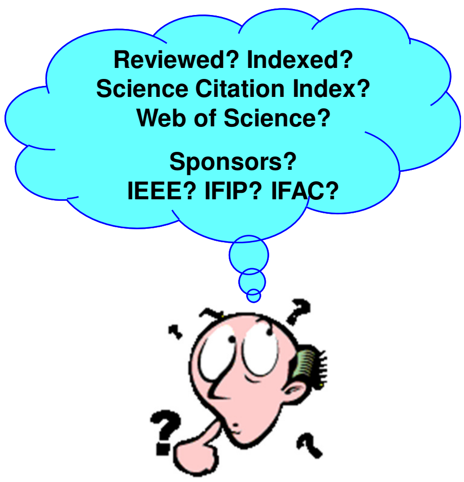
Consider multiple perspectives !



Step 7: Publish findings

- **A research result is not a contribution to the field if no one knows about it or can use it !**
- **Write scientific papers, make presentations**
  - **Intermediate results**
    - **Conferences**
    - **Collect feedback**
  - **Consolidated results**
    - **Journals**
  - **Be careful in selecting where you publish !**
- **Write dissertation**

"Publish or perish !"



Attributes of a good thesis

- It should be contestable, proposing an arguable point with which people could reasonably disagree.
  A strong thesis is **provocative**;
  it takes a stand and justifies the discussion you will present.
- It is **specific and focused**.
  A strong thesis proves a point without discussing "everything about …"
  Instead of music, think "American jazz in the 1930s" and your argument about it.
- It **clearly asserts your own conclusion** based on evidence.
  Note: Be flexible. The evidence may lead you to a conclusion you didn't think you'd reach. It is perfectly OK to change your thesis!
- It provides the reader with a map to guide him/her through your work.
- It anticipates and refutes the counter-arguments
- It **avoids vague language** (like "it seems").
- It avoids the first person. ("I believe," "In my opinion")
- It should pass the "**So what?** or **Who cares?**" test
  (Would your most honest friend ask why he should care or respond with "but everyone knows that"?)

For instance, "people should avoid driving under the influence of alcohol", would be unlikely to evoke any opposition.

https://www.kean.edu/~roneilfi/How%20to%20write%20a%20thesis%20statement.htm

Is it a good thesis ?

How do you know if you've got a solid tentative thesis?

Try these five tests:

1. **Does the thesis inspire a reasonable reader to ask, "How?" or Why?"**
2. **Would a reasonable reader NOT respond with "Duh!" or "So what?" or "Gee, no kidding!" or "Who cares?"**
3. **Does the thesis avoid general phrasing and/or sweeping words such as "all" or "none" or "every"?**
4. **Does the thesis lead the reader toward the topic sentences (the subtopics needed to prove the thesis)?**
5. **Can the thesis be adequately developed in the required length of the paper or dissertation?**

https://www.kean.edu/~roneilfi/How%20to%20write%20a%20thesis%20statement.htm

MORE: ■ **Can you "prove" it ?**

Most of this applies to the formulation of the research question and hypothesis as well!

Proof of concept

"Proof-of-Concept Prototype is a term that (I believe) I coined in 1984. It was used to designate a circuit constructed along lines similar to an engineering prototype, but one in which the intent was only to demonstrate the feasibility of a new circuit and/or a fabrication technique, and was not intended to be an early version of a production design. "

[Carsten, 1989]

http://en.wikipedia.org/wiki/Proof_of_concept

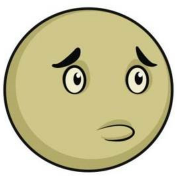
Proof of concept is a <u>short and/or incomplete realization</u> of a certain method or idea(s) to demonstrate its feasibility, or a demonstration in principle, whose purpose is to verify that some concept or theory is probably capable of exploitation in a useful manner. A related (somewhat synonymous) term is "proof of principle".

[Wikipedia]

In applied research a company presented with a project or proposal will often undertake internal research initially, to **prove that the core ideas are workable** and **feasible**, before going further. This use of proof of concept helps establish viability, technical issues, and overall direction, as well as providing feedback for budgeting and other forms of commercial discussion and control.

To some extent this applies to the prototyping work done in engineering PhD thesis work.

Presentation languages



- **Is it necessary to include many formulas and equations?**
  Is it "not-scientific" if not full of mathematics?

- **There are different "languages" used in different disciplines.**
  - **E.g. Mathematical formulas, Logical formulas / Set theory formalism, Formal specification languages (e.g. Z, Petri Nets), charts, semi-formal diagrams (e.g. UML), etc.**

- **Rigor does not necessarily require formal languages.**
  - **Do not include formulas just to impress the reader !**
    But be rigorous and systematic with what you write !!!
  - **Formal models are useful when the area is reaching a good maturity level and it is the time for knowledge consolidation.**
  - **When planning your research --- and also after analyzing the common practices in your field --- you need to consider the "language" to use.**

Role of simulation

- Simulation is an important tool in engineering and research.
  - In some areas it can cope for unafordable costs with physical experiments
  - It can also help when the performance of the experiment in the real world would take a long period of time (beyond the duration of the research project

- But be careful with its use:
  - How well does the simulation model reflect the reality?
  - You might be inferring conclusions based on "artificial worlds" ...

⚠ DANGER

Some people seem to believe that MATLAB is the real world!

Research or invention of new terms?

"The culture of computer science emphasizes novelty and self-containment, leading to a fragmentation where each research project strives to create its own unique world.

This approach is quite distinct from experimentation as it is known in other sciences — i.e. based on observations, hypothesis testing, and reproducibility — that is based on a presupposed common world.

But there are many cases in which such experimental procedures can lead to interesting research results even in computer science. "

[Feitelson, 2006]

This situation quite frequently affects the "policies" of research funding agencies !

4. ENGINEERING RESEARCH

Engineering and technological research

- In engineering and technological research we build novel artefacts to solve some problems.
  - But also give a contribution to the existing knowledge base of foundations and methodologies
  - and the communication of the contribution to the stakeholder communities.
- What is then a good method for this?
- How can we validate this research?

Design Science Research method


Hevner et al./Design Science in IS Research

MIS Quarterly — Research Essay

DESIGN SCIENCE IN INFORMATION SYSTEMS RESEARCH[1]

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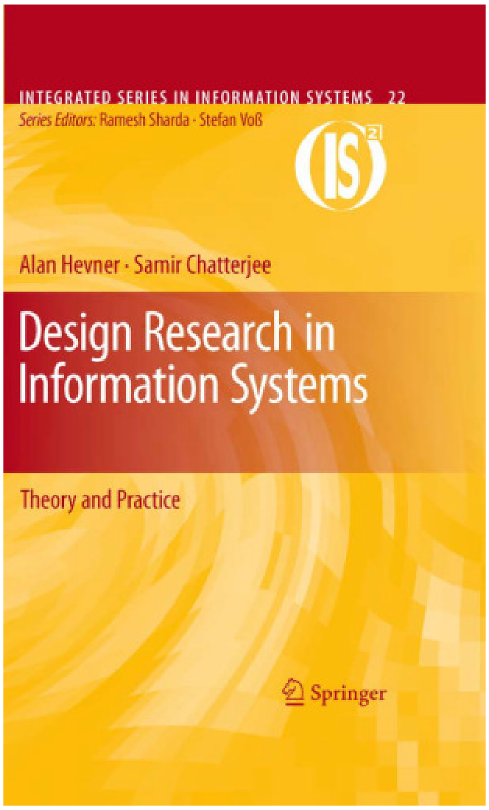
Abstract

Two paradigms characterize much of the research in the Information Systems discipline: behavioral science and design science. The behavioral-science paradigm seeks to develop and verify theories that explain or predict human or organizational behavior. The design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts. Both paradigms are foundational to the IS discipline, positioned as it is at the confluence of people, organizations, and technology. Our objective is to describe the performance of design-science research in Information Systems via a concise conceptual framework and clear guidelines for understanding, executing, and evaluating the research. In the design-science paradigm, knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artifact. Three recent exemplars in the research literature are used to demonstrate the application

[1]Allen S. Lee was the accepting senior editor for this paper.

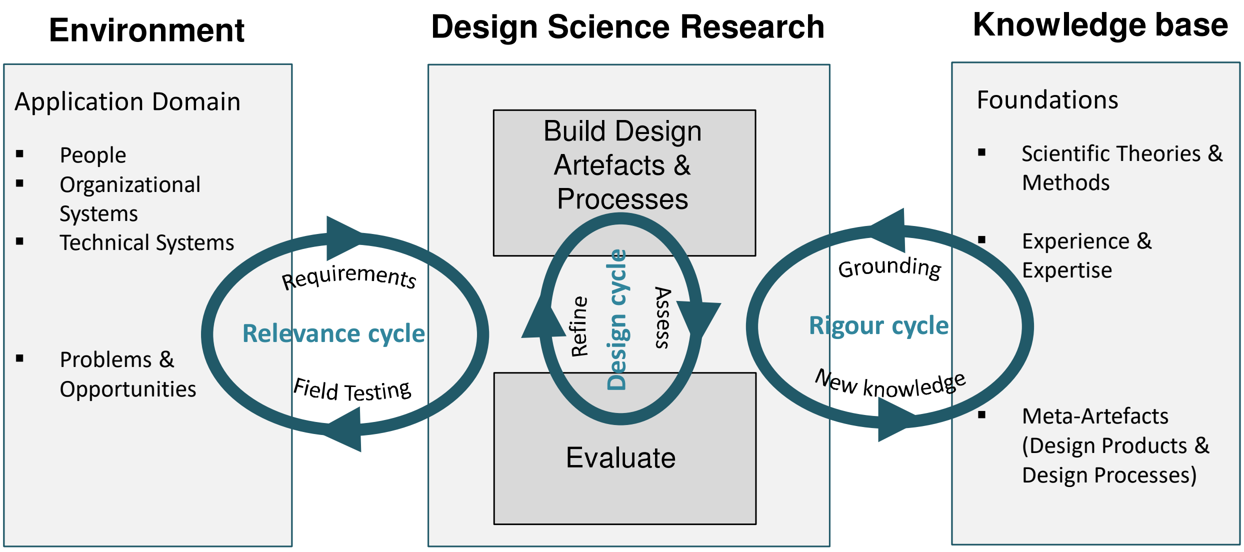
MIS Quarterly Vol. 28 No. 1, pp. 75-105/March 2004 75



Initially developed for the area of Information Systems, it can be applied to technological research in general

Design Science Research method

- ❑ **3 pillars**
- ❑ **3 cycles**



"*The design-science paradigm has its roots in engineering and the sciences of the artefact. It is fundamentally a problem-solving paradigm. It seeks to create innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, and use of information systems can be effectively and efficiently accomplished.*" [Hevner et al. 2004]

Design Science Research method …

Environment - the problem space in which phenomena of interest reside

Design Science Research - building artefacts that address needs evolving from the environment

Knowledge Base - provides Foundations and Methodologies from and through which research is achieved

Design Science Research method …

Relevance cycle:

- Begins with: an application domain / environment that provides the requirements for research (Problems & Potential opportunities), as well as defines the acceptance criteria for the validation of research results.
- Returns: the resulting artefact for study and validation against its utility, quality, and efficacy.

Feedback, as restated requirements, supports artefact adjustment.

Rigour cycle:

- Provides: the scientific knowledge to the research project to ensure proper scientific groundings (implies a search on the KB, making references to related work)
- Returns: additions to the KB

Design cycle:

- The artefact is conceived and evaluated ("lab evaluation") before it is submitted to the cycle of relevance and prior to its knowledge contribution for the cycle of rigor.

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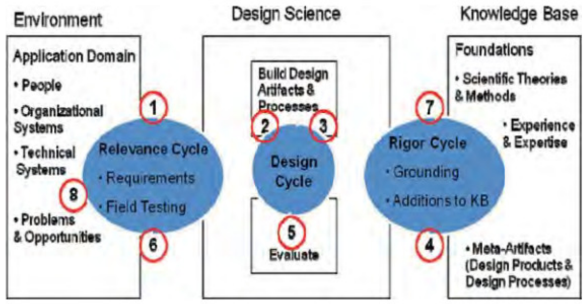
Design Science Research method ...

Checklist

1. What is the research question (design requirements)?
2. What is the artefact? How is the artefact represented?
3. What design processes (search heuristics) will be used to build the artifact?
4. How are the artefact and the design processes grounded by the knowledge base? What, if any, theories support the artefact design and the design process?
5. What evaluations are performed during the internal design cycles? What design improvements are identified during each design cycle?
6. How is the artefact introduced into the application environment and how is it field tested? What metrics are used to demonstrate artefact utility and improvement over previous artefacts?
7. What new knowledge is added to the knowledge base and in what form (e.g., peer-reviewed literature, meta-artefacts, new theory, new method)?
8. Has the research question been satisfactorily addressed?



[Hevner, Chatterjee 2010]

Design Science Research method ...

Steps:

A) Identification / Definition of the research theme and environment

B) Literature review / Related Work

C) Define the objectives for a solution

D) Artefact design and development

E) Artefact Validation / demonstration (internal / design validation)

F) Validation in environment

G) Communication (publication)

Design Science Research method …

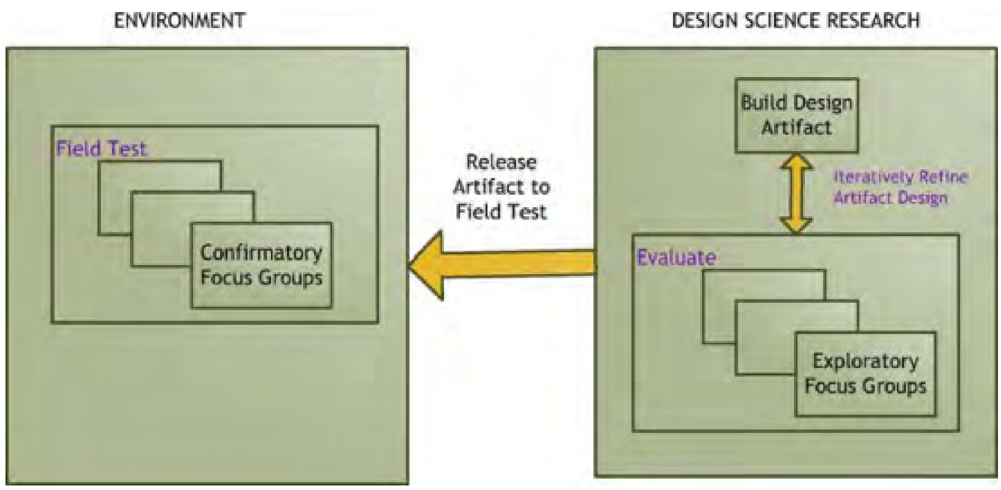
Avoiding Common Mistakes in Performance Evaluation

- *No goals*: Any endeavor without goals is bound to fail. The need for a goal may sound obvious, but many performance efforts are started without any clear goals (Jain 1991). A performance analyst and design team starts immediately to model or simulate the design. A common claim is that the model will be flexible enough to be easily modified to solve different problems. Experienced analysts know that there is no such thing as a general-purpose model. Each model must be developed with a particular goal in mind. Setting goals is not a trivial exercise.
- *Unsystematic approach*: Often analysts adopt an unsystematic approach whereby they select system parameters, factors, metrics, and workloads arbitrarily. This leads to inaccurate conclusions. The systematic approach is to identify a complete set of goals, system parameters, factors, metrics, and workloads.
- *Analysis without understanding the problem:* Many analysts feel that nothing is achieved without a model and numerical data in place. A large share of the analysis effort should go in to defining a problem. As they say, a problem well stated is half solved.
- *Incorrect performance metrics:* A common mistake is that analysts choose those metrics that can be easily computed or measured rather than the ones that are relevant.
- *Wrong evaluation techniques:* Analysts often have a preference of one technique over the other. Those proficient in queuing techniques will tend to change every performance problem to a queuing problem even if the system is too complex and easy to measure. The classic cliché "When you have a hammer, everything you see is a nail" applies to this mistake.

[Hevner, Chatterjee 2010]

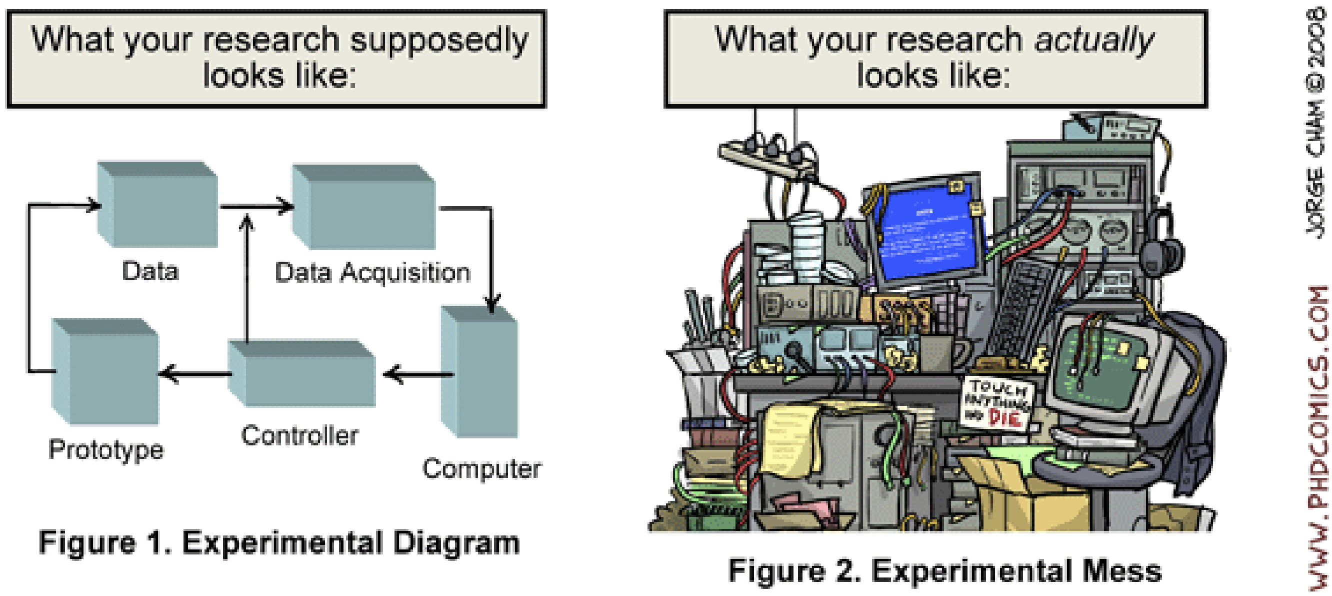
Design Science Research method …

Use of
Focus Groups
in Evaluation



[Hevner, Chatterjee 2010]

- **Number of Focus Groups**
- **Number of Participants**
- **Participant Recruitment**
- **Identify Moderator**
- **Develop and Pre-test a Questioning Route**
- **Conduct the Focus Group**
- **Analyze and Interpret Data**
- **Report Results**



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