



SCIENTIFIC RESEARCH METHODOLOGIES AND TECHNIQUES

Unit 2: SCIENTIFIC 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 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

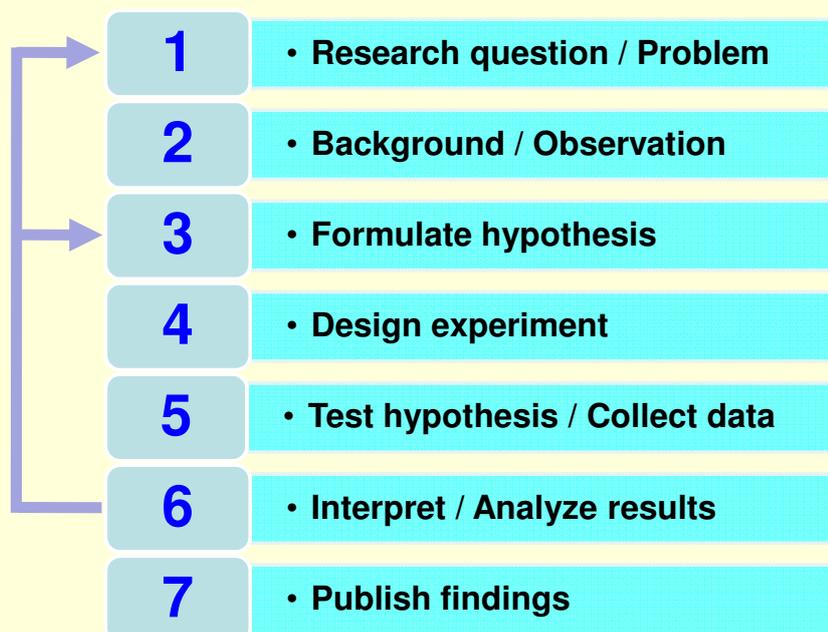
But there is no single, universal formal "scientific method". There are several variants and each researcher needs to tune the process to the nature of the problem and his / her working methods.



2. OVERVIEW OF RESEARCH METHODS

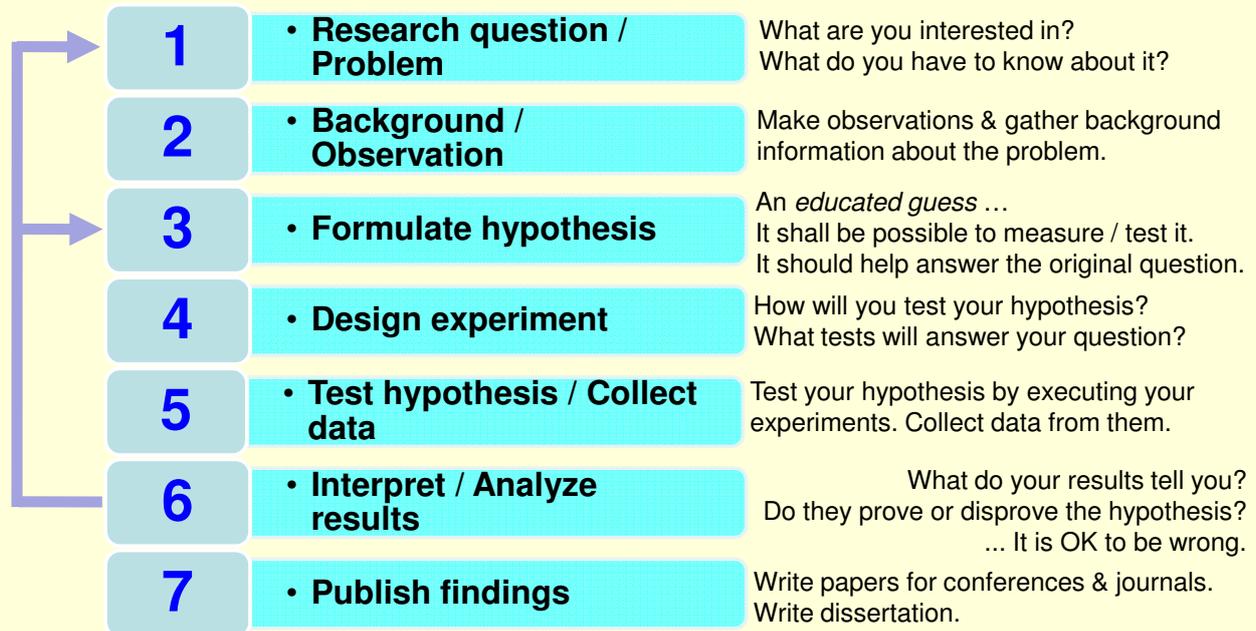


Classical phases

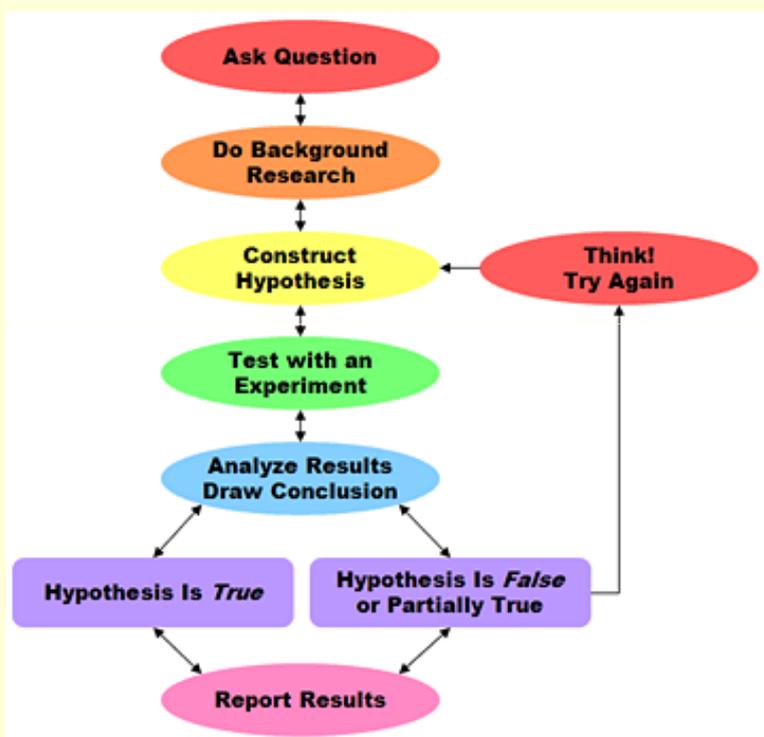




Classical phases ...



Other variants



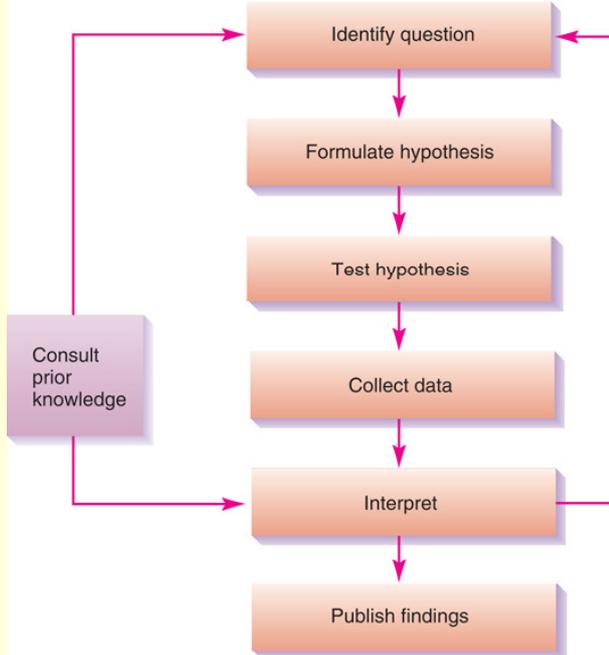
1. Define the question
2. Gather information and resources (observe)
3. Form hypothesis
4. Perform experiment and collect data
5. Analyze data
6. Interpret data and draw conclusions that serve as a starting point for new hypothesis
7. Publish results
8. Retest (frequently done by other scientists)

[Wikipedia]

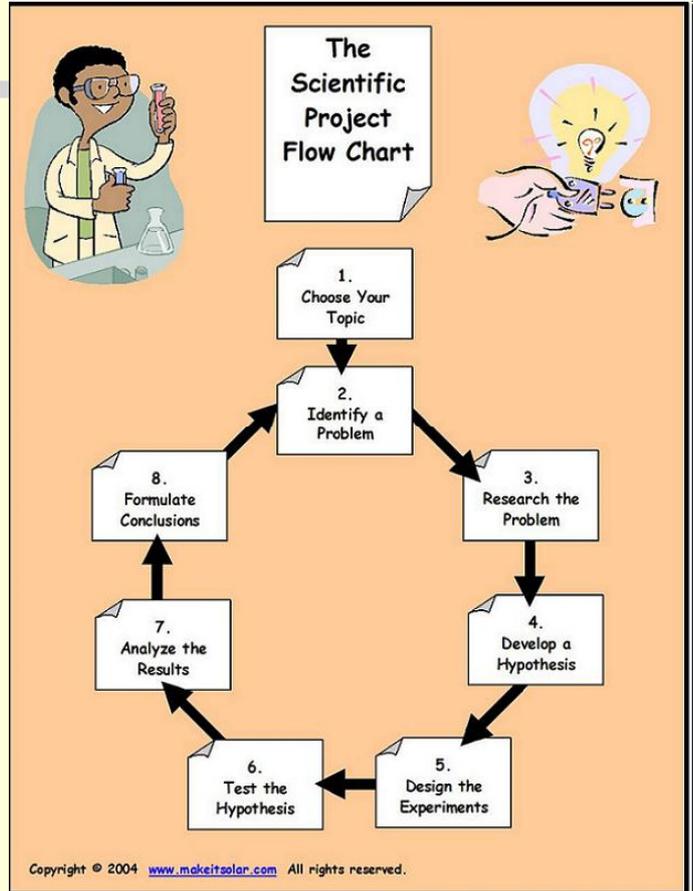


Other variants

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

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Other variants

1. **Observe** an event.
2. Develop a **model** (or **hypothesis**) which makes a **prediction**.
3. **Test** the prediction.
4. **Observe** the result.
5. **Revise** the hypothesis.
6. **Repeat** as needed.
7. A successful 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]

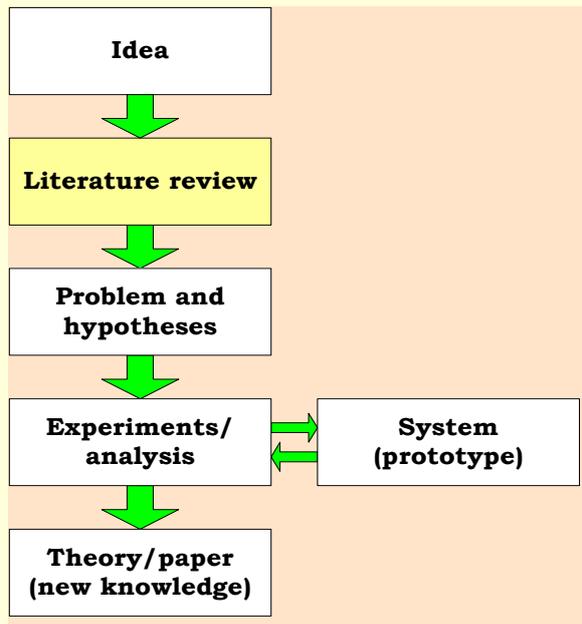
www.gallimorelearning.com/index_files/Powerpoint%20for%20website/Science%20PP/scientificmethod.ppt

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Other variants



[Mämmelä, 2006]

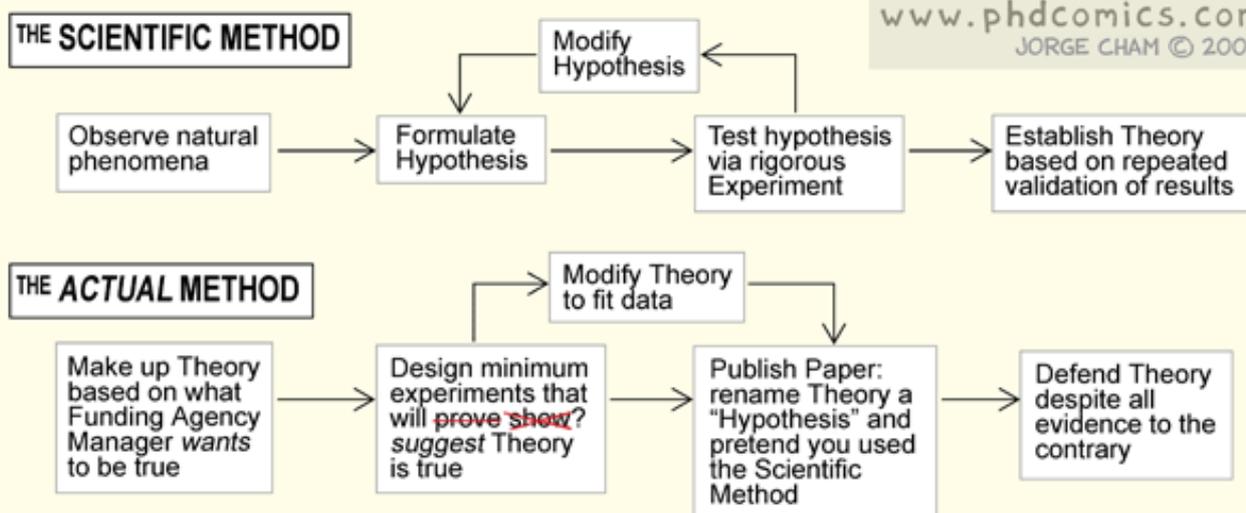
The Scientific Method Made Easy



<http://www.youtube.com/watch?v=zcavPAFiG14>



In practice !





Errors of experts who did not follow the Scientific Method

- ✦ "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.



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 like a hypothesis.
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.



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?”

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 network, 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 is not formulated as a research question ... and 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?

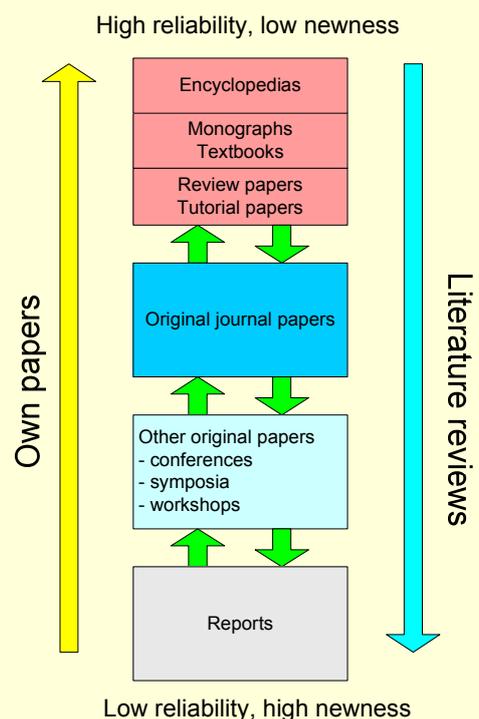
Too many, no hierarchy, some redundancy.

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Step 2: Background / Observation

- How has the work been done previously? What similar work has been leading up to this point?
 - Study 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]

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Step 3: Formulate hypothesis

- A scientific hypothesis states the ‘predicted’ (educated guess) relationship amongst variables.
- Serve to bring clarity, specificity and focus to a research problem
 - ... But are 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.
- A possible format (formalized):
“If then (because) “
- 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”.



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.



Hypothesis example

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

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)

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

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

“**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.”



Step 4: Design experiment

- Includes planning in detail 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 not only design a prototype / system but also 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



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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.

Young or old lady?



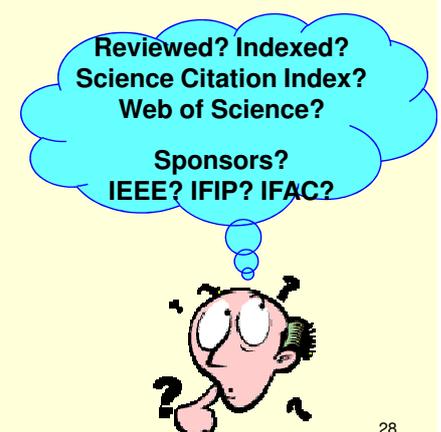
**Consider
multiple
perspectives !**

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

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.

<http://www.sdst.org/shs/library/thesis.html>



Is it a good thesis ?

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

Try these five tests:

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

<http://www.sdst.org/shs/library/thesis.html>

MORE: ■ Can you “prove” it ?



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 short and/or incomplete realization 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 **unaffordable 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” ...



Experimental computer science

Experimental computer science and engineering (ECSE) refers to the building of, or the experimentation with or on, nontrivial hardware or software systems

[National Academy Press report, 1994]

Is Computer Science really an Experimental Science?

- Computer Science is “not a science, but a synthetic, an engineering discipline” [Brooks]:
 - Phenomena are manufactured
 - CS is a type of engineering
 - So experimentation is misplaced
- But other Sciences:
 - Study manufactured entities, e.g., super-heavy elements, lasers
 - Make inferences about models, e.g. simulations

[Gain, 2008]

Without experiments, computer science is in danger of drying up and becoming an auxiliary discipline.

[Tichy, 1998]



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 !

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ECS - Fallacies

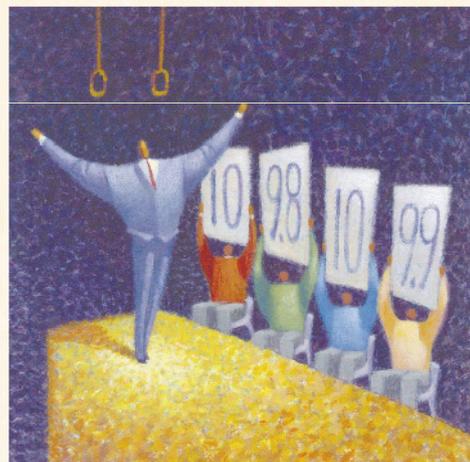
[Gain, 2008]

Fallacy #1: Traditional scientific method isn't applicable Fallacy #2: Current levels of experimentation are enough

- Subject of inquiry is information unlike traditional sciences which study matter or energy
- Example:
 - Object-oriented programming, is it genuinely better?
- In a study of CS papers requiring empirical backup, 40-50% had none
- Compared to <15% in non-CS papers
- The youth of CS as a discipline is not sufficient justification



Rebuttal: To understand information processes, computer scientists must observe phenomena, formulate explanations, and test them. This *is* the scientific method.



Rebuttal: Relative to other sciences, the data shows that computer scientists validate a smaller percentage of their claims.



ECS – Fallacies ...

[Gain, 2008]

Fallacy #3: Experiments cost too much

- Experiments can be expensive, but:
 - Often cheaper than the alternative
 - The cost may be worthwhile for important questions (general relativity)
 - Explore cheaper options (benchmarking)



Rebuttal: Meaningful experiments can fit into small budgets; expensive experiments can be worth more than their cost.

Fallacy #4: Demonstration will suffice

- Demos allow proof of concept and illustrate potential
- But they cannot provide solid evidence



Rebuttal: Demos can provide incentives to study a question further. Too often, however, these demos merely illustrate a potential.

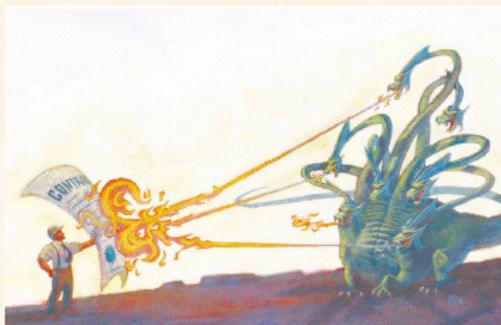


ECS – Fallacies ...

[Gain, 2008]

Fallacy #5: There's too much noise in the way

- Too many variables, effects swamped by noise
- Answers:
 - Use benchmarks
 - Apply statistical controls from medicine and psychology



Rebuttal: Fortunately, benchmarking can be used to simplify variables and answer questions.

Fallacy #6: Experimentation will slow progress

- Research takes longer → fewer ideas
- Actually weeds out questionable ideas and their offshoots
- Still a place for the hypothesis paper



Rebuttal: Increasing the ratio of papers with meaningful validation has a good chance of actually accelerating progress.



ECS – Fallacies ...

[Gain, 2008]

Fallacy #7: Technology changes too fast

- “The rate of change in computing is so great that by the time results are confirmed they may no longer be of any relevance” [Mudge]
- Look to fundamental long term problems rather



Rebuttal: If a question becomes irrelevant quickly, it is too narrowly defined and not worth spending a lot of effort on.

Fallacy #8: There are substitutes

- Theory
 - Can be contradicted in practice by incorrect simplifying assumptions
- Intuition
 - Fails in the face of counterintuitive results
 - E.g., productivity is NOT necessarily improved by typechecking
- Experts
 - Science must always be backed up by evidence
 - E.g., claims about cold fusion



ECS – Misconceptions

[Denning, 1980]

Misconception 1: *It is not novel to repeat an experiment.*

- Many proposals are rejected because a reviewer said: "That's already been done." Many others have never been submitted because the proposer feared such a response.
- In other areas (e.g. Physics, Chemistry, Biology, and Medicine) it is customary that different groups repeat an important experiment under slightly different conditions or with slightly different methods -- to see if it can be independently corroborated.
Results are not accepted by the community unless they have been independently verified.

A typical syndrome in ICT research in Europe !



ECS – Misconceptions ...

[Denning, 1980]

Misconception 2: *Mathematics is the antithesis of experiment.*

- “Theory *versus* practice”
“Mathematicians *versus* practitioners.”
"Once a theorem is proved, there's no point in re-proving it,"
"Once a thing is built, there's no point in theorizing about it."

But the whole point of science is to discover which *ideas* are important.

Experiments are essential:

- to understand *ideas* and
- to convince others of their value.

Once an *idea* is assimilated by the community, the experiments behind it may be forgotten.

- This is true even of mathematics:
Results are re-proved to improve understanding of the underlying principles, the best theorems have many proofs, and social processes with empirical overtones help identify and simplify the best concepts.

History shows clearly that science and mathematics are complementary.
People *like* to theorize about important ideas!



ECS – Misconceptions

[Denning, 1980]

Misconception 3: *Tinkering is experimental science.*

(We use the word "hacking," rather than "tinkering," in our field.)

Unless it seeks to support a hypothesis, tinkering is not science.

It is not *science* to assemble parts to "see what happens."

Undirected work wanders aimlessly, finding interesting results only by accident; it produces "researchers" with spotty and erratic records.

Directed work, systematic testing, and dogged scientific perseverance have traditionally characterized the most productive researchers.

"Hacking" is not experimental computer science: It may improve the personal knowledge of the hacker, but it does not contribute to our sum of knowledge. Indeed, many interesting results have been discovered serendipitously. But many more have been discovered by systematic, persistent workers. Tinkering is the exception, not the rule, in productive research.

Risks:

- that funds being allocated for experimental research will be used merely for hacking.
- of discouraging conceptual work. Tinkering is no substitute for thinking.

What your research supposedly looks like:

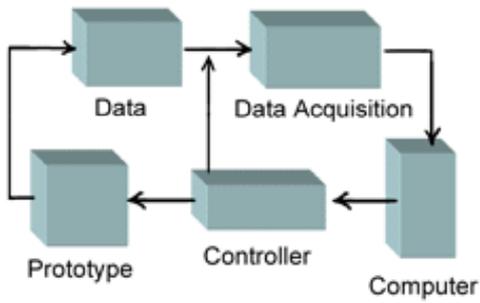


Figure 1. Experimental Diagram

What your research *actually* looks like:

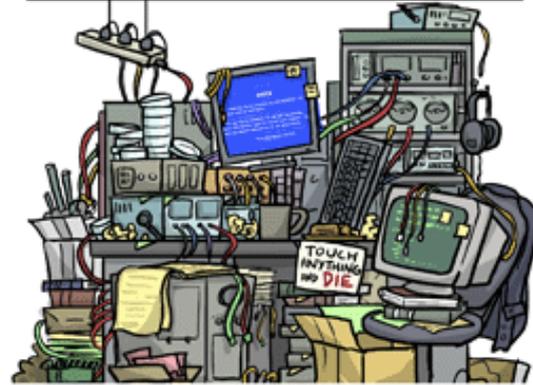


Figure 2. Experimental Mess

WWW.PHDCOMICS.COM JORGE CHAM © 2008

4. ENGINEERING RESEARCH

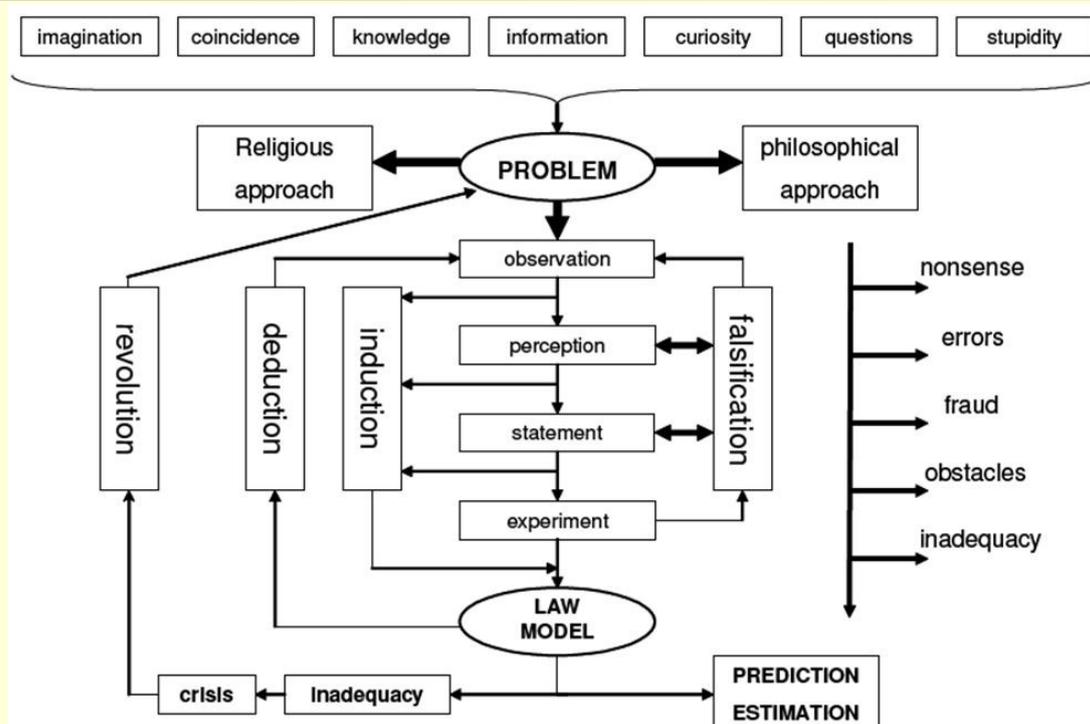


Scientist vs Engineer

- A scientist sees a phenomenon and asks “why?” and proceeds to research the answer to the question.
- An engineer sees a practical problem and wants to know “how” to solve it and “how” to implement that solution, or “how” to do it better if a solution exists.
- A scientist builds in order to learn, but an engineer learns in order to build.



Research methods in engineering





Research methods in engineering ...

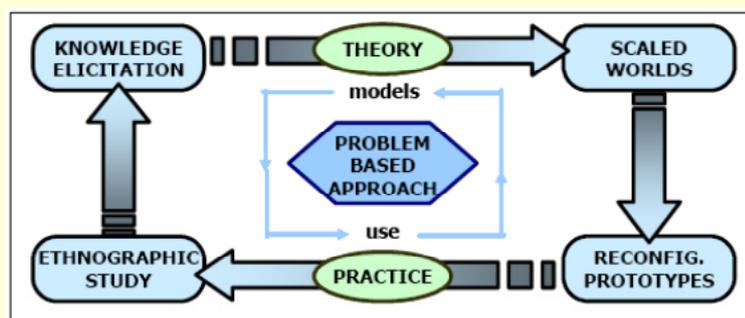


[Muller, 2008]

<http://www.gaudisite.nl/SEresearchValidationSlides.pdf>



Research methods in engineering ...

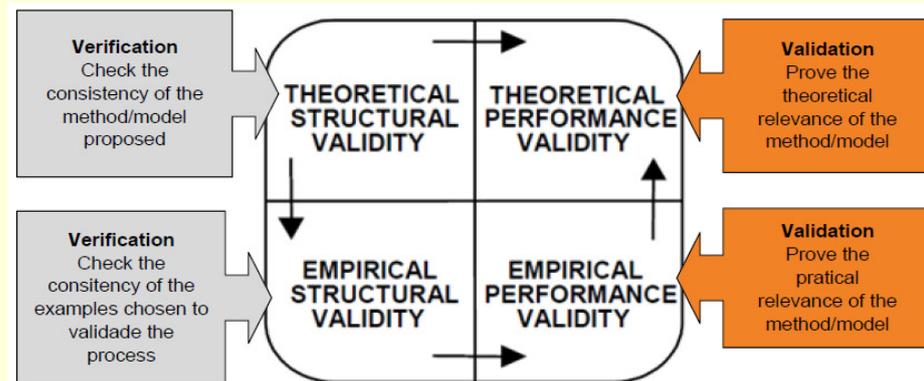
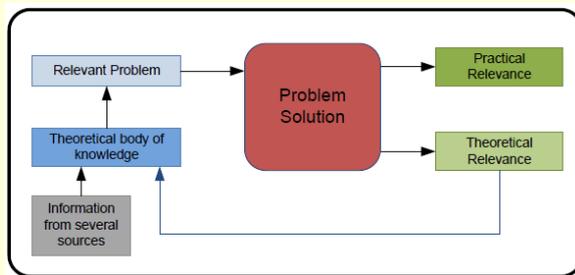


Systematic Evaluation Approach (McNeese (2003))

“McNeese has developed a systematic approach that links ethnography studies (direct observations of analysts/users in field environments), formal knowledge elicitation to develop cognitive maps of user analysis activity, creation of a scaled world environment, and evaluation of prototype cognitive aids and visualization tools using human subjects in a “living laboratory” approach.”

[Hall et al., 2006]

<ftp://ftp.rta.nato.int/PubFullText/RTO/MP/RTO-MP-IST-063/MP-IST-063-10.pdf>



(Pedersen et al. 2000)
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