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Design and Analysis of Experiments

01 - What is Science

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"*Science and everyday life cannot and should not be separated.*"

Rosalind Franklin (1920 – 1958)
English Chemist and X-ray crystallographer

Image: https://commons.wikimedia.org/wiki/File:Rosalind_Franklin_CC-BY-SA.png

What is science?

Some common misconceptions

- Science is a collection of facts; ×
- Science is the creation of new gadgets; ×
- Scientific ideas are absolute and unchangeable; ×
- Scientific ideas are subject to change, therefore unreliable; ×
- Observations give answers directly to the scientists; ×
- Science **proves** stuff; ×
- Science can only **disprove** stuff; ×
- The scientist works to **show** that his/her theory is right; ×

- Facts *vs* hypotheses *vs* theories *vs* laws;

Essential reading: Common Misconceptions About Science: `http://goo.gl/TN7k9B`

Image: `http://xkcd.com`

What is science?

A good operational definition

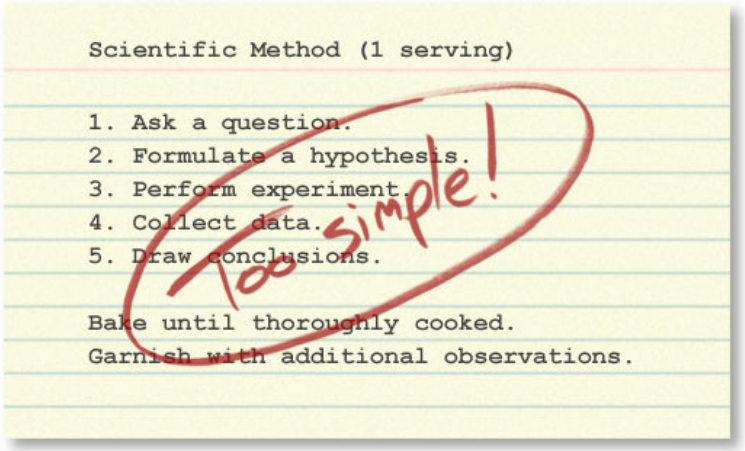
> *"What do you think science is?*
> *There's nothing magical about science.*
> *It is simply a systematic way for carefully*
> *and thoroughly observing nature and*
> *using consistent logic to evaluate results."*
>
> – Steven P. Novella

Image: `http://www.relativelyinteresting.com/definition-science-steven-novella/`

What is science?

The scientific process

- Normally shown as a flowchart or a sequence of steps;
- Oversimplification of a complex and iterative process;
- Suggests an “end” to the process.

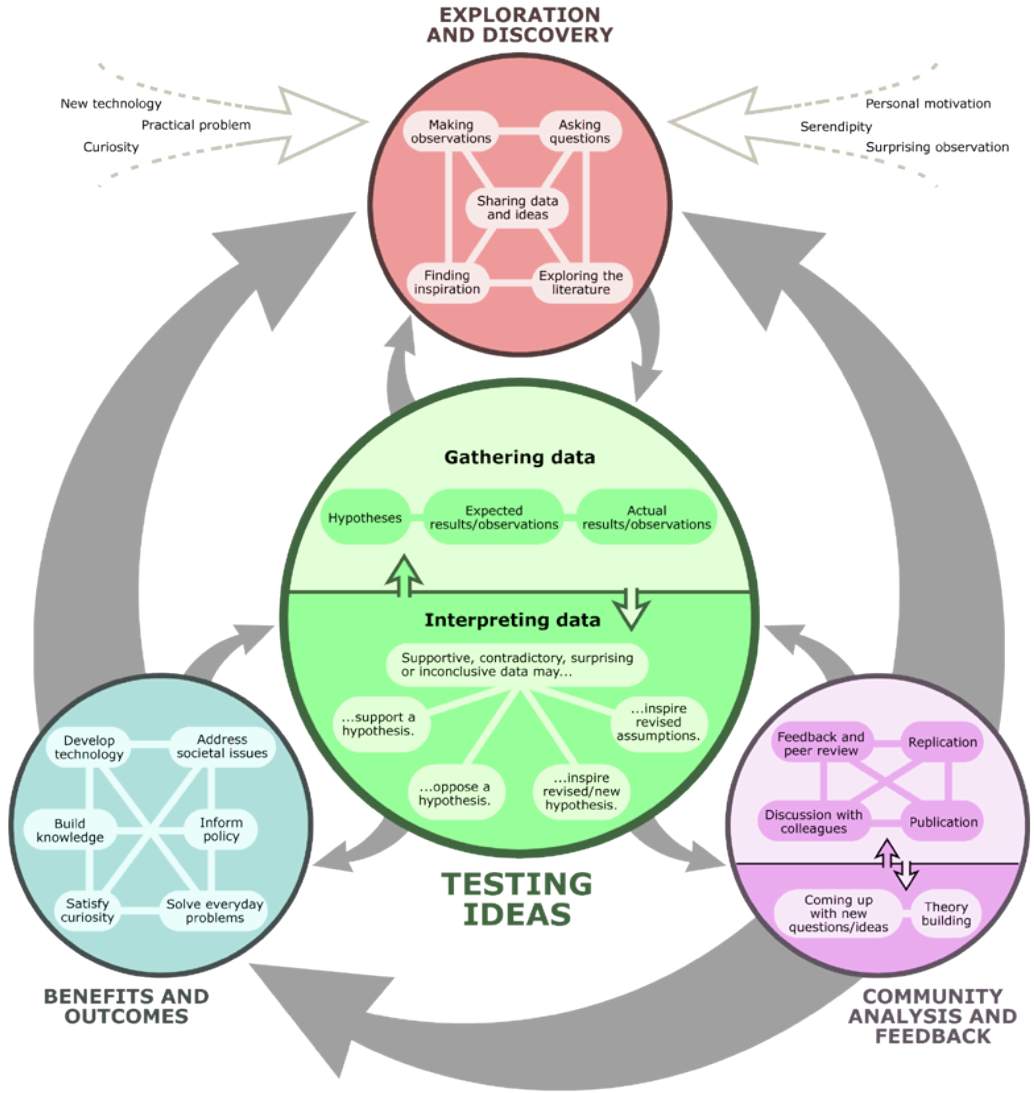


- Actually includes:
  - Several activities, performed at different stages;
  - Interaction with the scientific community;
  - Creative, “outside the box” thinking;
  - Preliminary conclusions, subject to revision as new and better data become available;
  - Learning from failures as much as from successes.

Image: `http://goo.gl/7cCGaz` - (c) Understanding Science, 2015. Used with permission.

What is science?

The scientific process



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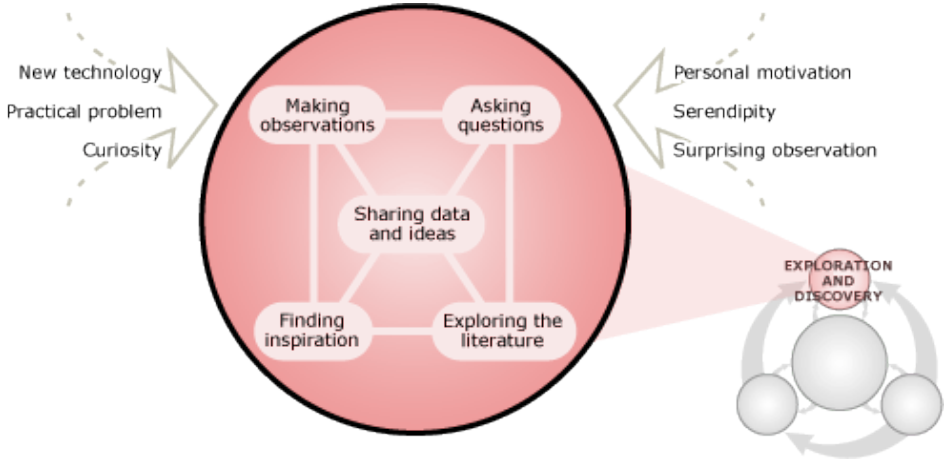
What is science?

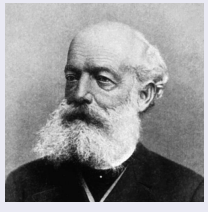
The scientific process

"*Dans les champs de l'observation le hasard ne favorise que les esprits pr?par?s.*" – **Louis Pasteur** (Univ. Lille, France, 1854).

- Observations $\rightarrow$ **questions**;
- Exploratory experimentation;
- Preparation + serendipity.

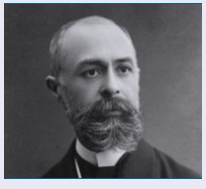


Benzene (1865)



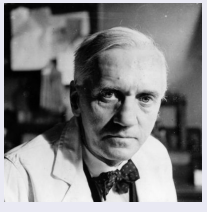
Kekule

Radioactivity (1896)



Becquerel

Penicillin (1928)



Fleming

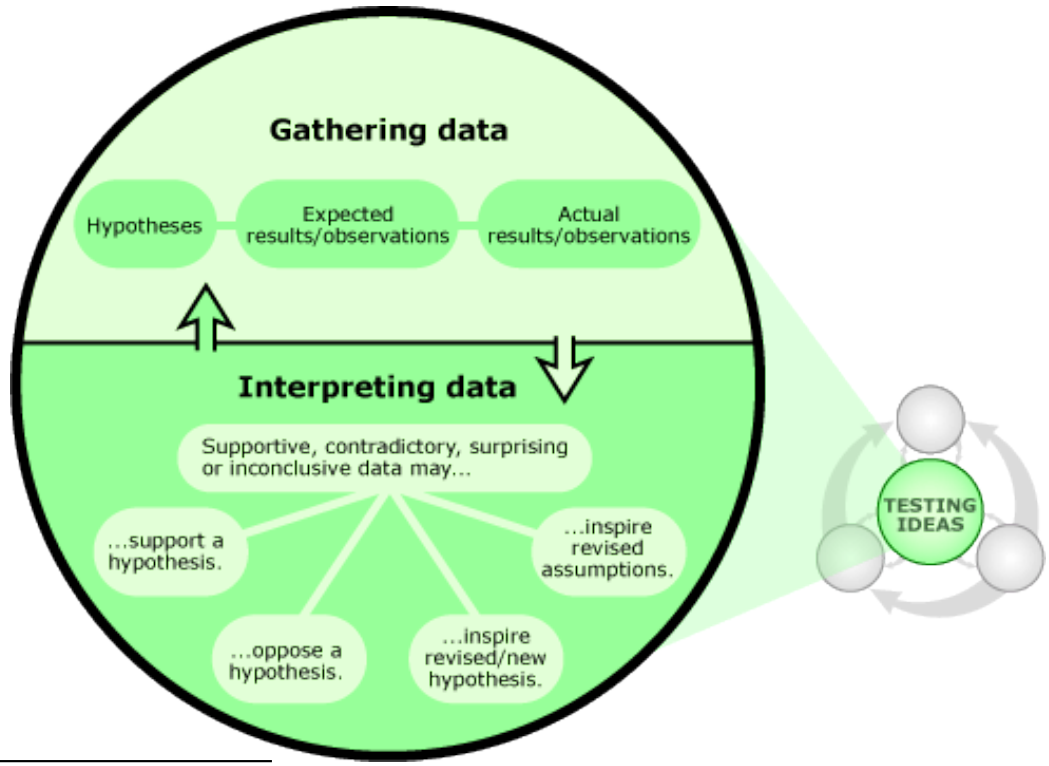
Top image: `http://goo.gl/fy8Glh` - (c) Understanding Science, 2015. Used with permission.

Scientists: `http://goo.gl/SG6sgp` | `http://goo.gl/rhLC9C` | `http://goo.gl/CFj8Ml`

What is science?

The scientific process

- Drawing and testing hypotheses;
- Comparing alternative explanations;
- Accepting / rejecting ideas based on **evidence**;
- **Predictions** *versus* **observation**: corroboration or refutation?



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What is science?

The scientific process

James Lind (1747):

- Observation: scurvy in sailors;
- Conjecture: Caused by the body rottenning;
- Idea: attempt to avoid/reverse effects with acidic substances;

Separation of a group of 12 affected sailors in six groups with identical diets, except for the addition of a supplement:

Group 1	Group 2	Group 3
Cider.	Vitriol.	Vinegar.
Group 4	**Group 5**	**Group 6**
Sea water.	Oranges and lemons.	Tea.

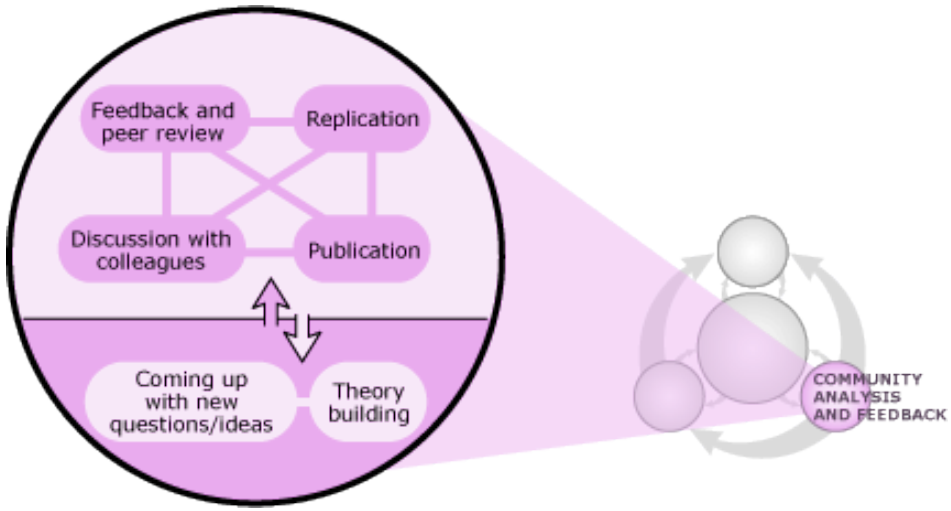
Image: `http://commons.wikimedia.org/wiki/File:James_Lind_by_Chalmers.jpg`

What is science?

The scientific process

Interaction with the scientific community is **fundamental**:

- Colleagues;
- Collaborators;
- Reviewers;
- Rivals;

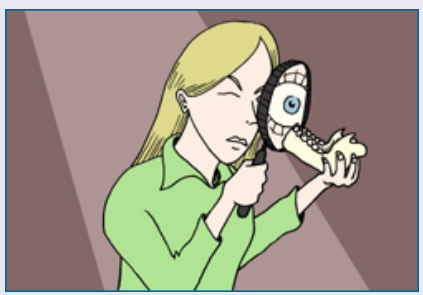


This interaction plays essential roles for the progress of research:

Criticism

Inspiration

Vigilance



Motivation

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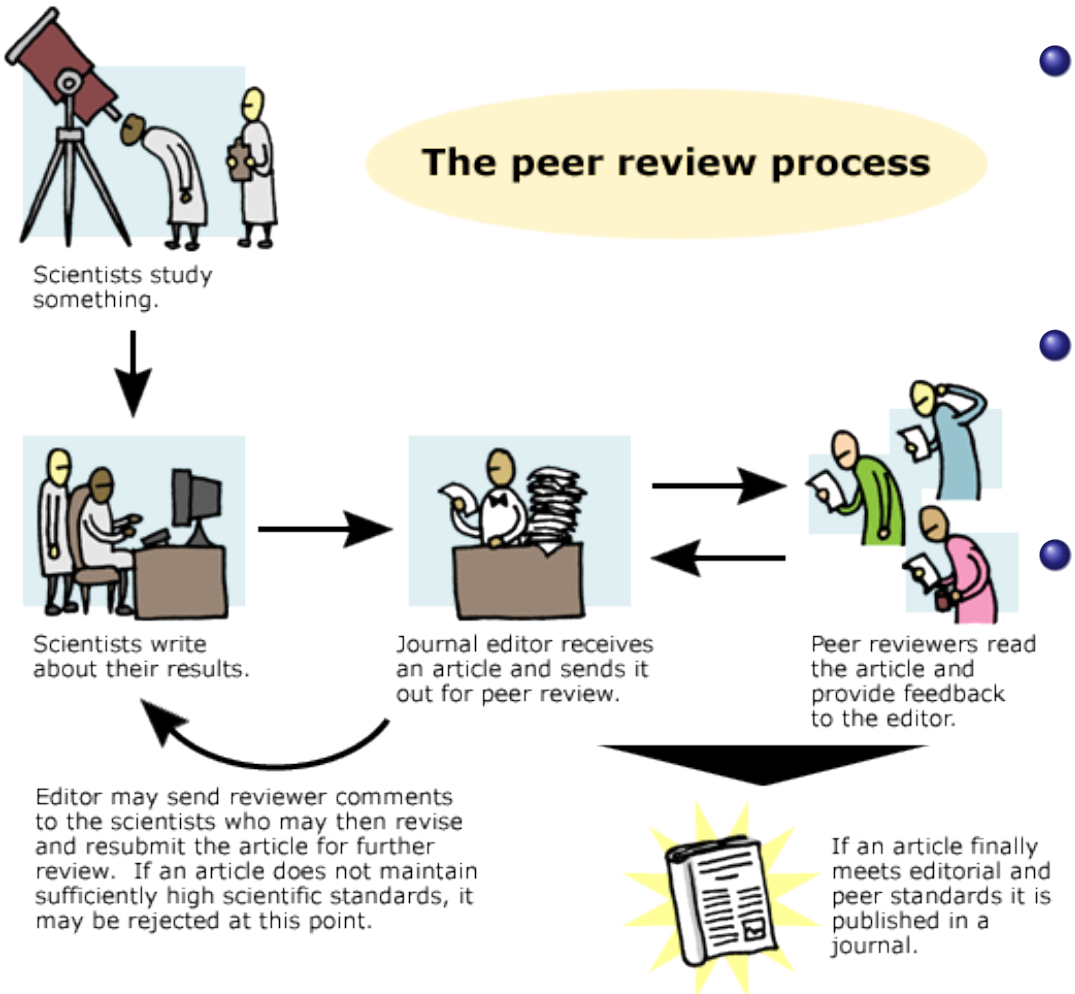
What is science?

The scientific process

Publication and peer review.



- Additionally, *post-publication review* by the wider scientific community;
- **Replication** and verification of results;
- **Reproducibility** is essential.

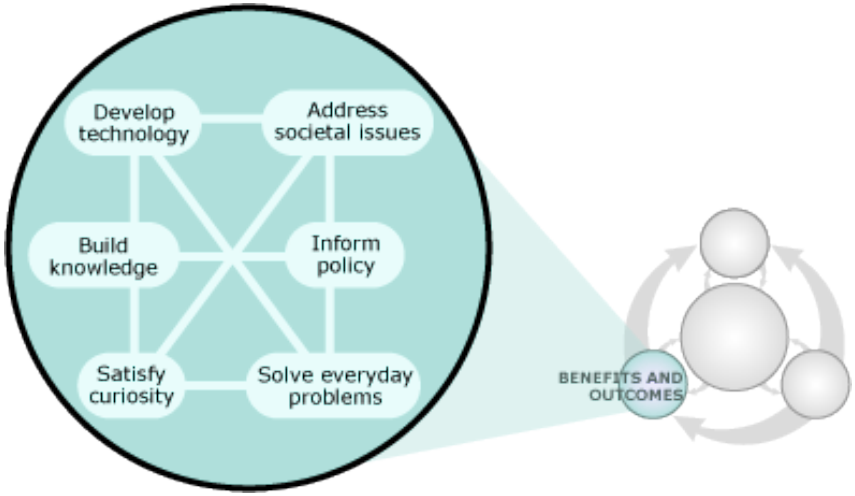
Image: `http://goo.gl/VWCVkK` - (c) Understanding Science, 2015. Used with permission.

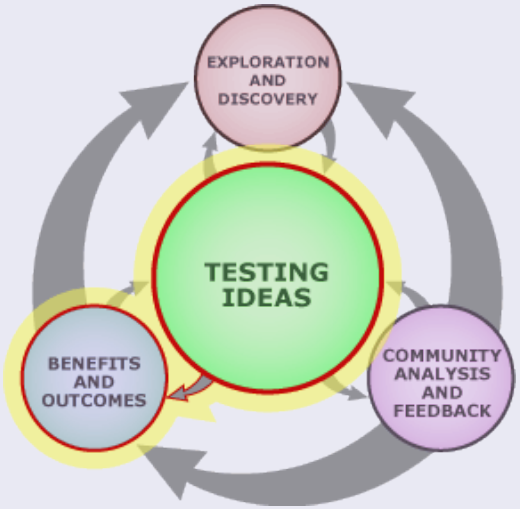
What is science?

The scientific process

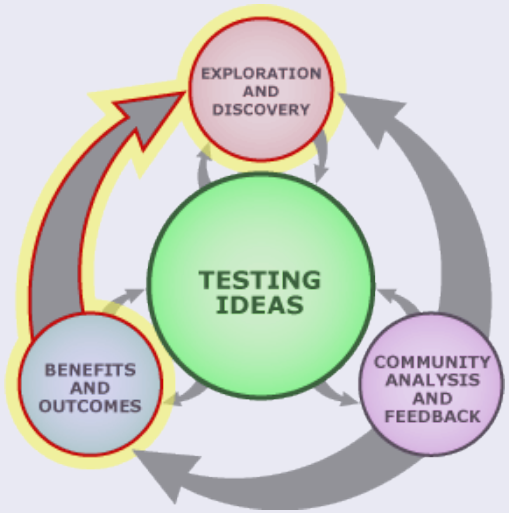
The scientific process is a way of building knowledge:

- Generate and test new ideas about how the world works;
- Iteratively increasing the reliability of the knowledge;

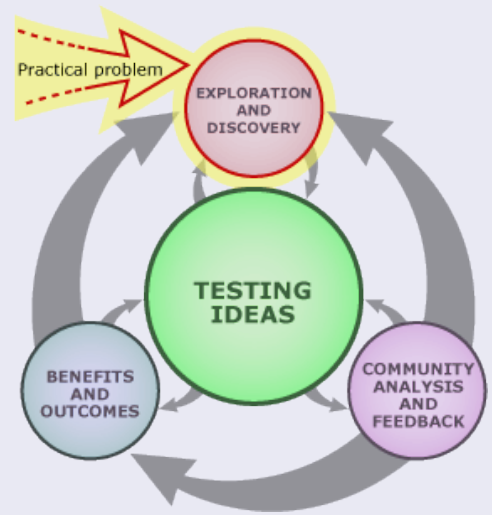




Knowledge→Applications



Technologies→Discovery



Applications→Investigation

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What is science?

To wrap it up

> "*It is important to be literate in the scientific method, not only for the sake of your own research. We are also agents of change in the population and, as such, we need to be aware of good and bad science, and able to point the difference to the society.*"
>
> – Claus C. Aranha

Image: `http://lattes.cnpq.br/2897895256340893`

Bibliography

Required reading

1. *Understanding Science*. 2014. University of California Museum of Paleontology. 3 January 2014. - `http://www.understandingscience.org`
2. F.L.H. Wolfs, *APPENDIX E: Introduction to the Scientific Method*. - `http://goo.gl/osGpU`

Recommended reading

1. Carl Sagan,*The demon-haunted world: science as a candle in the dark*, Random House, 1996.
2. The Skeptics Guide to the Universe. - `http://www.theskepticsguide.org`

About this material

Conditions of use and referencing

Please reference this work as:

Felipe Campelo (2018), *Lecture Notes on Design and Analysis of Experiments*.
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