

# What is Science?

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**NYT B01**

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# Agenda

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1. What is science?
2. Theory building and validation
3. Science as a social system
4. Programs and projects
5. Science and society
6. Research ethics

# **1. What is Science?**

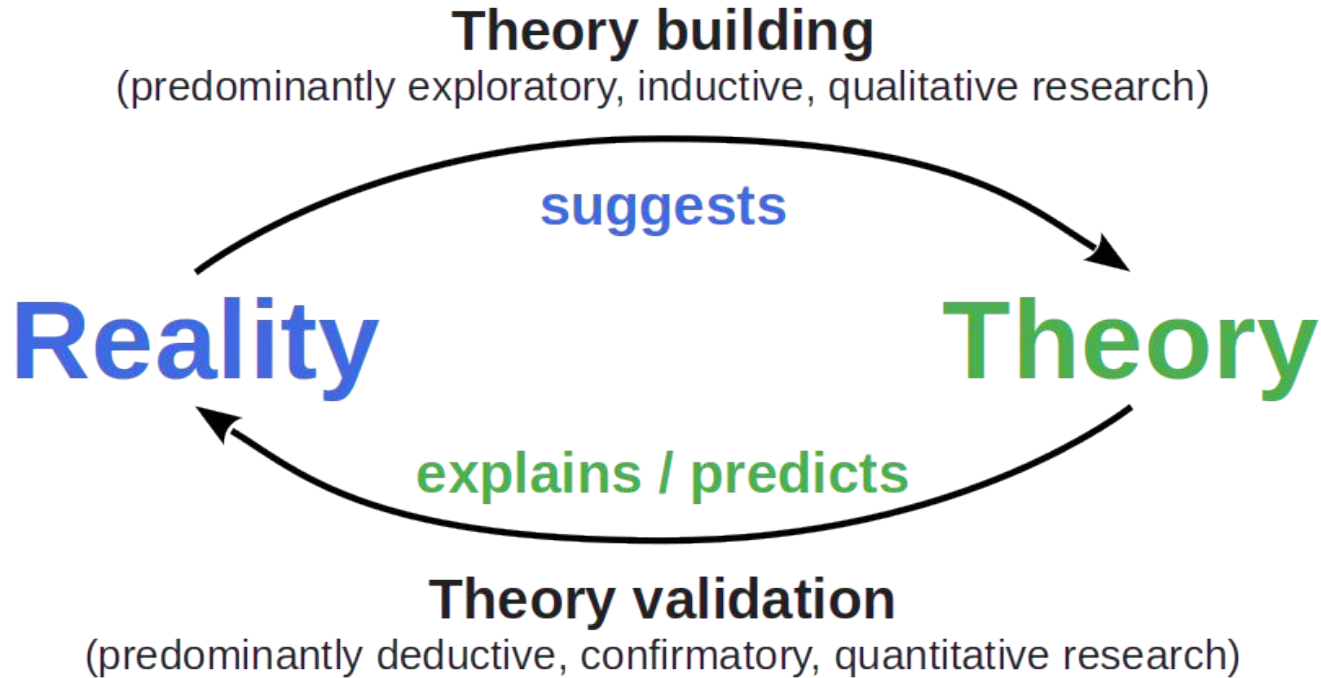
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# Definition of Science (Working Definition, Recap)

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**Science** is the process of acquiring knowledge for correct prediction and reliable outcome. [DR]

# The Logic and Process of Science



# Epistemological Stances

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**Objectivism** (truth is independent of the observer and can be known)

1. **Positivism / empiricism** (truth can be determined and verified through observation)
2. **Rationalism** (some truths don't follow from observation but rather logical thought)

**Constructivism** (truth depends on the observer and is socially negotiated)

# Theory and Reality

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A scientific **theory** is a model / framework / equation / ...

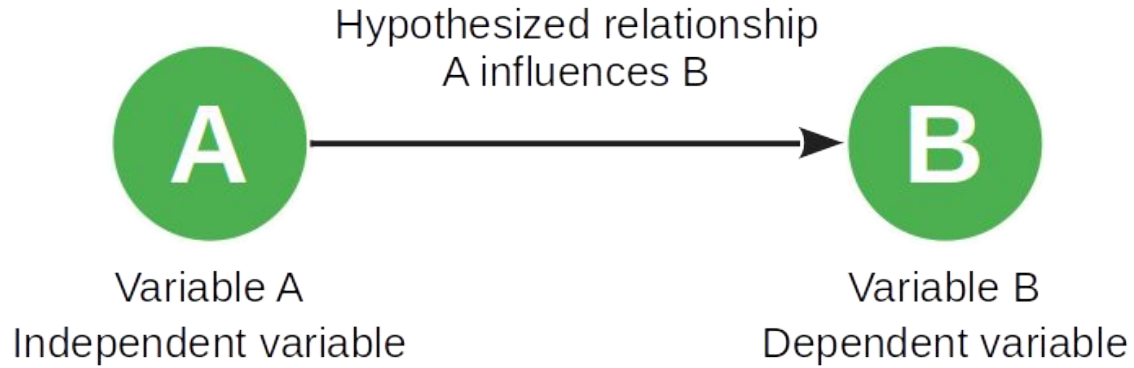
- That can be used to create **hypotheses**

A scientific **hypothesis** is a

- Testable true/false statement about **reality**

In the smallest case, a (generalized) hypothesis is a theory

# The Minimal Theory





# Maxwell's Equations [1] of (Classic) Electromagnetism

Name	Integral equations	Differential equations
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E} \cdot d\mathbf{S} = \frac{1}{\varepsilon_0} \iiint_{\Omega} \rho \, dV$	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B} \cdot d\mathbf{S} = 0$	$\nabla \cdot \mathbf{B} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d}{dt} \iint_{\Sigma} \mathbf{B} \cdot d\mathbf{S}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 \left( \iint_{\Sigma} \mathbf{J} \cdot d\mathbf{S} + \varepsilon_0 \frac{d}{dt} \iint_{\Sigma} \mathbf{E} \cdot d\mathbf{S} \right)$	$\nabla \times \mathbf{B} = \mu_0 \left( \mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$

# Structural Equation Model of Sense of Virtual Community [1]

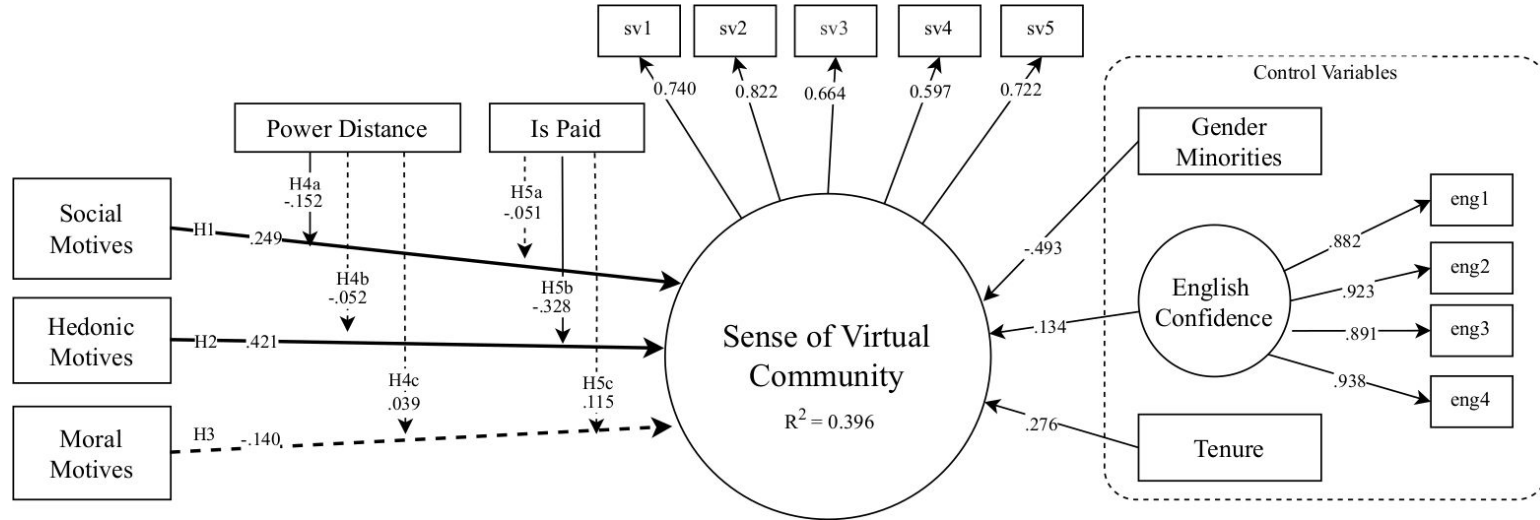
H1: Social motives → SVC

H2: Hedonistic motives → SVC

H3: Moral motives → SVC

H4abc: Power distance x (H1, H2, H3 → SVC)

H5abc: Is paid for work x (H1, H2, H3 → SVC)



# Classification of Sciences (by Subject)

## Formal Sciences

- Mathematics, ...

Takes a formal approach

## Natural Sciences

- Physics, chemistry, biology, ...

Takes an empirical approach

## Social Sciences

- Psychology, sociology, political science, ... More likely to take an analytical approach

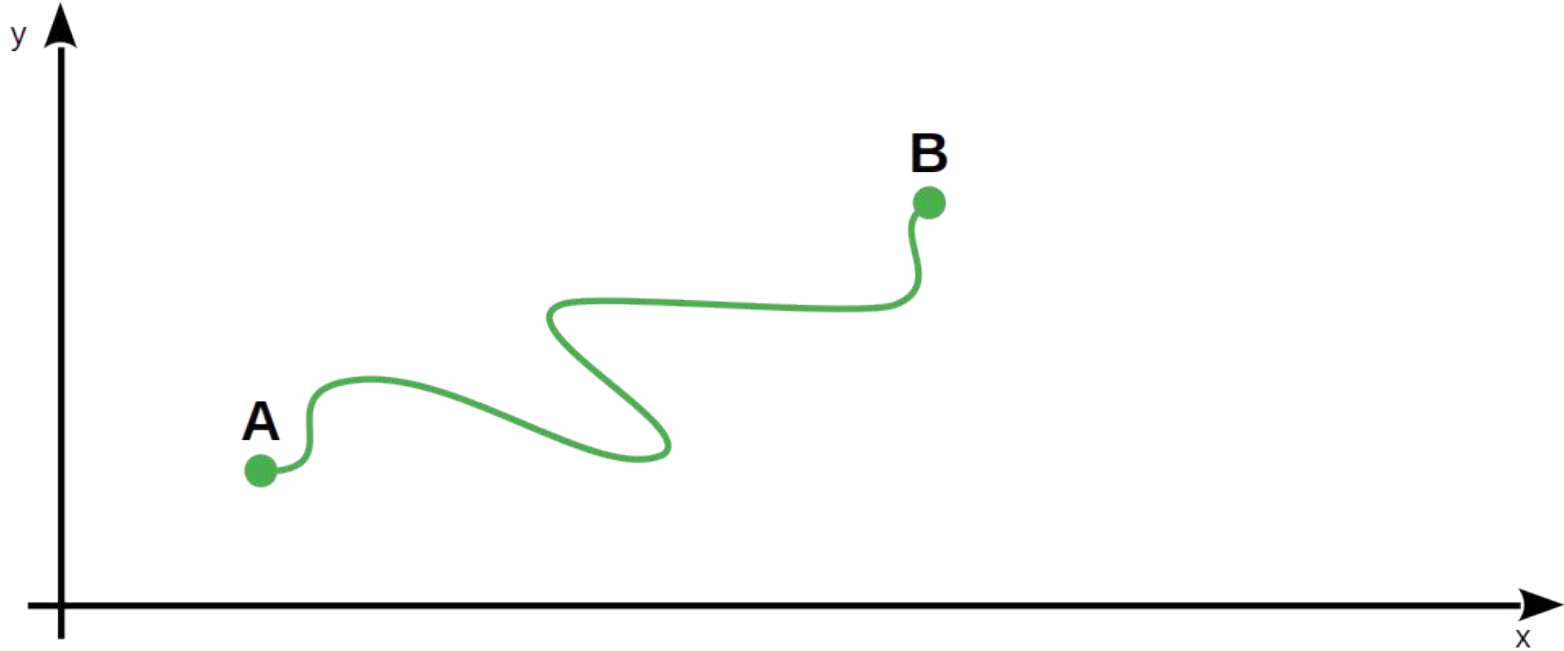
## Applied Sciences

More likely to take a design science approach

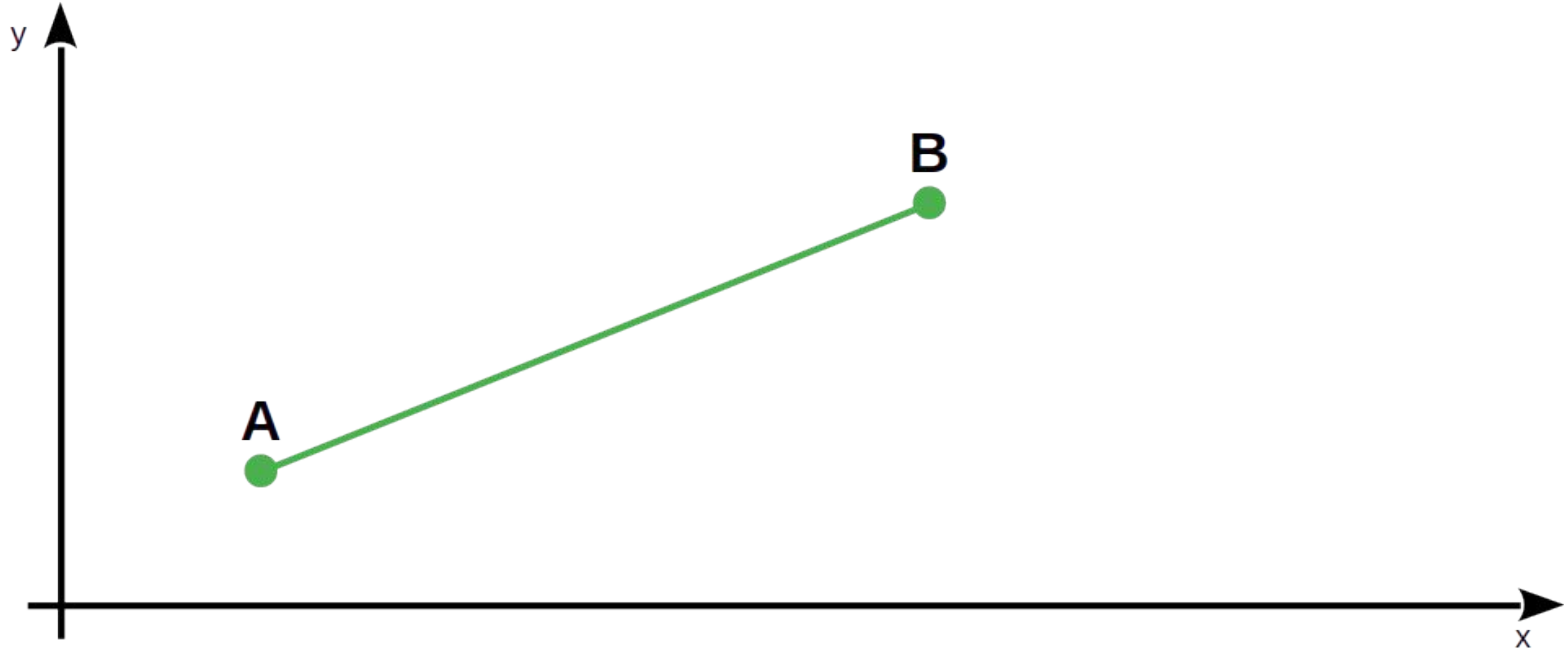
- Mechanical engineering, computer science, information systems, ...



# Solving a Problem vs. Building a Theory



# Using a Theory to Solve a Problem



# Science vs. Engineering [1]

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## Science is

- as defined before (“build to learn”, design science research)

## Engineering is

- The application of scientific principles (“learn to build”)

## **2. Theory Building and Validation**

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# Theory Building and Validation

## Theory building is

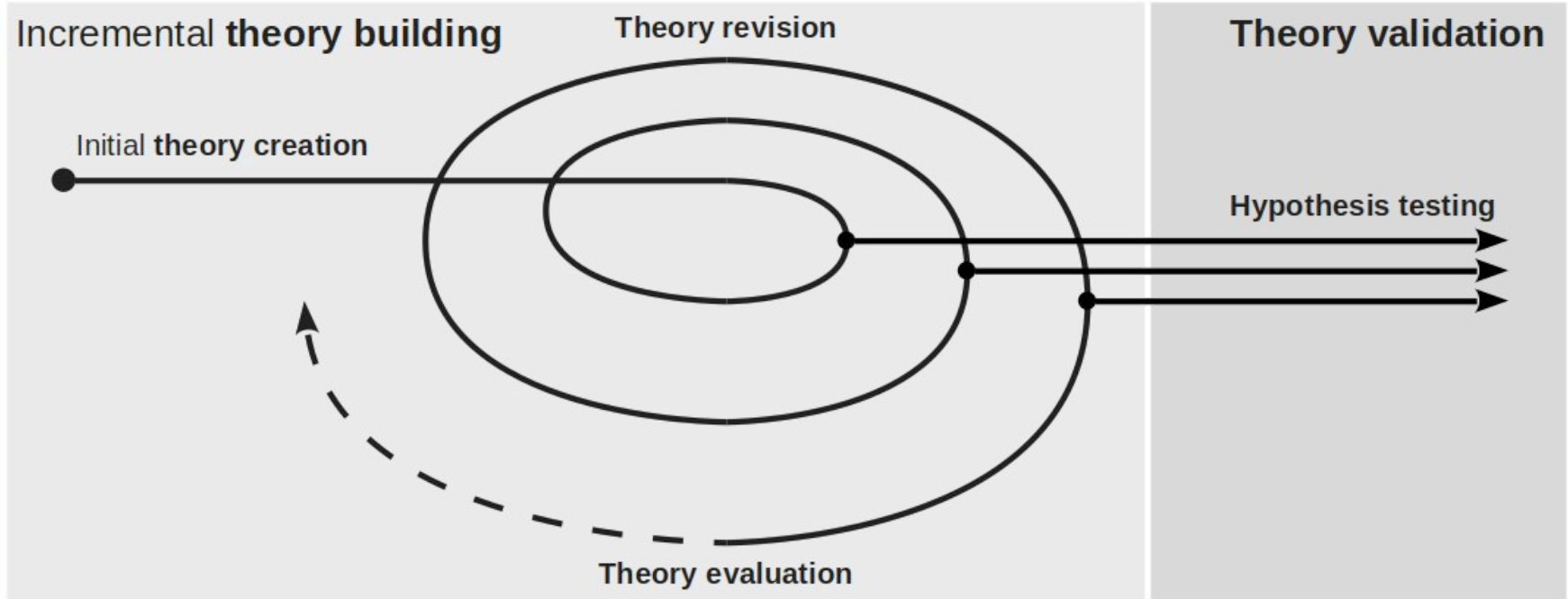
- The process of creating and revising (building out) a theory
  - Initial creation
  - Subsequent evaluation
  - Continued revision and evaluation

## Theory validation is

- The process of testing a theory through its hypotheses



# Interaction of Theory Building and Validation [1]



# Theory Evaluation vs. Validation [DR]

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## Theory evaluation is

- The assessment of a theory for the purposes of revising it

## Theory validation is

- The testing of a theory to confirm it / find holes

Many researchers (sloppily) use these terms interchangeably

# Exploratory and Confirmatory Research

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**Exploratory research is**

- Theory building research

**Confirmatory research is**

- Theory validation (testing) research

# Inductive vs. Deductive Research

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## **Inductive research is**

- Research that finds patterns in data to derive a theory

## **Deductive research is**

- Research that creates and tests hypotheses from theory

# Qualitative vs. Quantitative Research

## Qualitative research is

- Research that works with **qualitative data** which is
  - Data collected for characterization using qualitative insight
  - Not easily measured and counted

## Quantitative research is

- Research that works with **quantitative data** which is
  - Data collected for generalization through statistical analysis
  - Numerical in some way

# Process of Theory Building and Validation

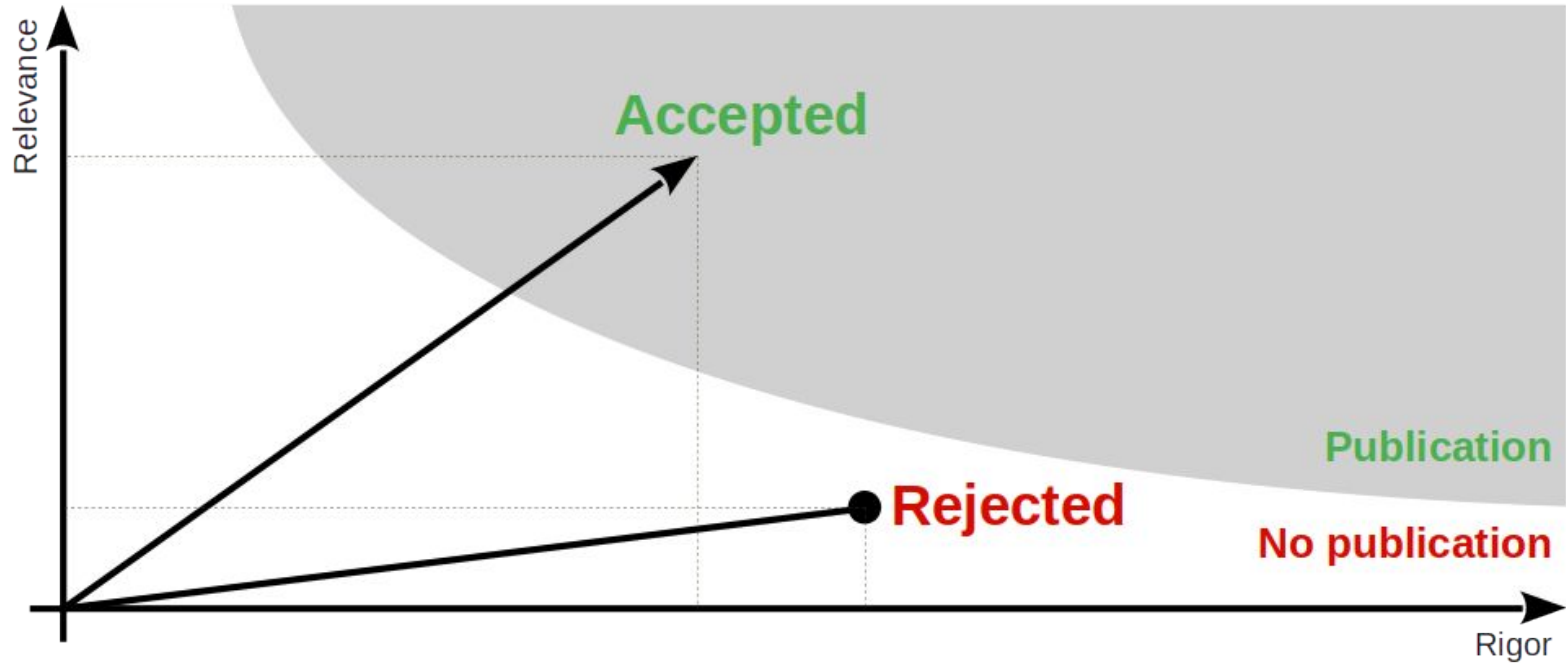
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The process is almost always incremental and iterative

In science, there are at least three major scopes of iterations

1. While building out a single theory on a subject
2. While building out a paradigm through interrelated theories
3. While replacing an old paradigm with a new one

# Rigor vs. Relevance



### **3. Science as a Social System**

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# Scientific Communication

## A research paper is

- A (written) article published in an accredited publication outlet like
  - Academic journals
  - Conference proceedings
  - Special events / outlets

## Other forms of scientific communication

- Research grant proposals
- Opinions, letters to the editor
- Public and private peer reviews

# Scientific Quality Assurance

## A **peer review** is

- The quality assessment of scientific communication by a peer
- Where a peer is another scientist

## A **review process** is

- The overall quality assessment of some scientific writing
  - Based on (several) peer reviews and
  - Editorial / committee deliberation

## The number of **paper citations** is

- The count of other research papers referencing your work
- A key metric in assessing impact (not necessarily quality)

# Who Can be a Researcher / Scientist?

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Everyone.

We are all peers.

Some are more peer than others.

## **4. Programs and Projects**

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# Program and Project Hierarchy

Role	Level	Purpose
Sponsor	Theme	<ul style="list-style-type: none"><li>• Defines a research theme</li><li>• Funds programs within the theme</li></ul>
Program manager	Program	<ul style="list-style-type: none"><li>• Applies for managing a program</li><li>• If chosen, manages the program</li></ul>
Principal investigator	Projects	<ul style="list-style-type: none"><li>• Applies for a project within a program</li><li>• If accepted, carries out the project</li></ul>

# Example Parties

Role	Example
Sponsor	DFG, BMBF, BMWK, ...
Program manager	DFG, DLR, VDI/VDE
Principal investigator	Any scientist

# Example Theme, Program, and Projects

Level	Example
Theme	<ul style="list-style-type: none"><li>• Innovation in software engineering</li></ul>
Program	<ul style="list-style-type: none"><li>• Improving programmer productivity</li></ul>
Projects	<ul style="list-style-type: none"><li>• How to use chat AIs for code generation?</li><li>• Is static typing superior to dynamic typing?</li></ul>

# The Role of Students in Research Projects

Role	Responsibility
Principal investigator	<ul style="list-style-type: none"><li>• Project / research agenda</li></ul>
Graduate researcher	<ul style="list-style-type: none"><li>• Major component in project</li></ul>
Final thesis student	<ul style="list-style-type: none"><li>• Contribution to major component</li></ul>



## **5. Science and Society**

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# The Nobel Prize [1] in Chemistry (2020)

Emmanuelle Charpentier

[The Nobel Prize in Chemistry 2020](#)

Prize motivation: “for the development of a method for genome editing”



Jennifer A. Doudna

[The Nobel Prize in Chemistry 2020](#)

Prize motivation: “for the development of a method for genome editing”



[1] See <https://www.nobelprize.org/>

# The ACM's A.M. Turing Award [1] (1999)



## PHOTOGRAPHS

### BIRTH:

April 19, 1931, Durham, North Carolina,  
United States

### EDUCATION:

AB, Duke University (1953– physics); SM,  
Harvard University (1955 – computer

## FREDERICK ("FRED") BROOKS



United States – 1999

### CITATION

For landmark contributions to computer architecture, operating systems, and software engineering.



SHORT  
ANNOTATED  
BIBLIOGRAPHY



RESEARCH  
SUBJECTS



ADDITIONAL  
MATERIALS



VIDEO  
INTERVIEW

**Frederick Phillips Brooks, Jr. was born April 19, 1931, in Durham, North Carolina.** Growing up in the Raleigh/Durham region, he earned his AB in physics at Duke University in 1953. Brooks then joined the pioneering degree program in computer science at Harvard University, where he earned his SM in 1955 and his PhD in 1956. At Harvard he was a student of Howard Aiken, who during World War II developed the [Harvard Mark I](#), one of the largest electromechanical calculators ever built, and the first automatic digital calculator built in the United States.

# The 2009 Ig Nobel Prizes [1]

VETERINARY MEDICINE PRIZE: [Catherine Douglas](#) and [Peter Rowlinson](#) of Newcastle University, Newcastle-Upon-Tyne, UK, **for showing that cows who have names give more milk than cows that are nameless.**

REFERENCE: “[Exploring Stock Managers’ Perceptions of the Human-Animal Relationship on Dairy Farms and an Association with Milk Production](#),” [Catherine Bertenshaw \[Douglas\]](#) and [Peter Rowlinson](#), Anthrozoos, vol. 22, no. 1, March 2009, pp. 59-69. DOI: 10.2752/175303708X390473.

PEACE PRIZE: Stephan Bolliger, [Steffen Ross](#), [Lars Oesterhelweg](#), [Michael Thali](#) and [Beat Kneubuehl](#) of the University of Bern, Switzerland, **for determining — by experiment — whether it is better to be smashed over the head with a full bottle of beer or with an empty bottle.**

REFERENCE: “[Are Full or Empty Beer Bottles Sturdier and Does Their Fracture-Threshold Suffice to Break the Human Skull?](#)” Stephan A. Bolliger, Steffen Ross, Lars Oesterhelweg, Michael J. Thali and Beat P. Kneubuehl, Journal of Forensic and Legal Medicine, vol. 16, no. 3, April 2009, pp. 138-42. DOI:10.1016/j.jflm.2008.07.013.

PUBLIC HEALTH PRIZE: [Elena N. Bodnar](#), Raphael C. Lee, and Sandra Marijan of Chicago, Illinois, USA, **for inventing a [brassiere that, in an emergency, can be quickly converted into a pair of protective face masks](#), one for the brassiere wearer and one to be given to some needy bystander.**

REFERENCE: U.S. patent # 7255627, granted August 14, 2007 for a “[Garment Device Convertible to One or More Facemasks](#).”



[1] See <https://improbable.com/>

## **6. Research Ethics**

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# Research, the Researcher, and Ethics

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Your ethics as well as ethical standards provide criteria of what and what not to do

You are your own agent and cannot delegate (or hide from) responsibility

# Escalation Levels of Responsibility

Party	Country	Program sponsor	Principal investigator	Individual researcher
Laws	X	X	X	X
Ethical standards		X	X	X
Project obligations			X	X
Personal value system				X

# Ethical Conduct in Software Engineering Research [1]

## **Informed consent** is given

- When a participant received all relevant information and explicitly agreed to participate

## **Scientific value** is given

- When relative to other work the combined rigor and relevance outweighs the competition

## **Beneficence** is given

- When the expected gains far outweigh any harms that might result from the research

## (Sufficient) **confidentiality** is given

- When participants remain anonymous and data confidential to the extent possible



# DFG's Safeguarding Good Scientific Practice [1]

1. Good scientific practice
2. Institutional rules
3. Organization
4. Young scientists
5. Impartial counselors
6. Performance evaluation
7. Data handling
8. Procedure for suspected misconduct
9. Cooperation of institutes
10. Learned societies
11. Authorship
12. Scientific journals
13. Guidelines for research proposals
14. Rules for the use of funds
15. Reviewers
16. Ombudsman for science

# MPG's Rules for Safeguarding Scientific Practice [1]

1. General principles of scientific practice
2. Cooperation and leadership responsibility within working groups
3. Guidance to junior scientists
4. Securing and storing primary data
5. Data protection
6. Scientific publications
7. Conflicts of interest between science and industry
8. Appointing ombudspersons
9. Whistleblower protection

# Summary

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1. What is science?
2. Theory building and validation
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4. Programs and projects
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6. Research ethics

# Thank you! Any questions?

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