What is Science?

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Agenda

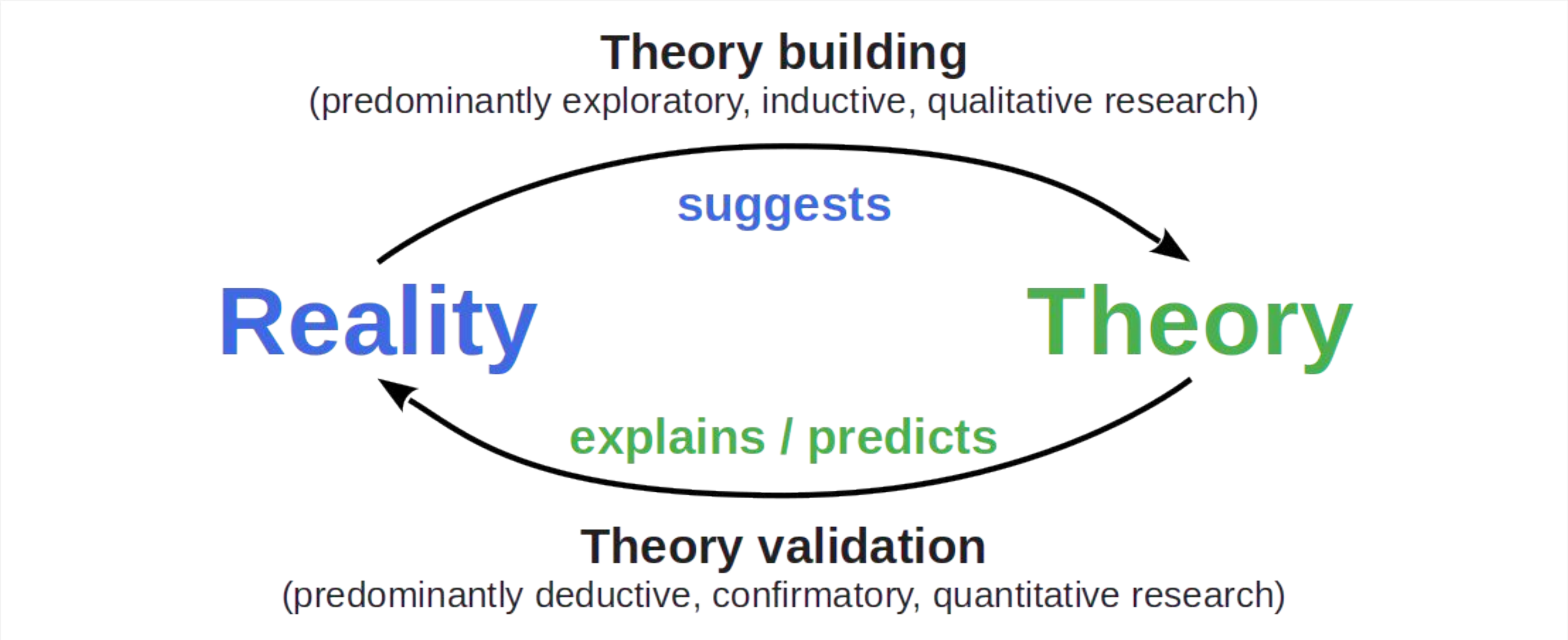
1. What is science?
2. Theory building and validation
3. Science as a social system
4. Programs and projects
5. Science and society
6. Research ethics

1. What is Science?

Definition of Science (Working Definition, Recap)

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

The Logic and Process of Science



Epistemological Stances

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

A scientific **theory** is a model / framework / equation / calculus / …

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

A scientific **hypothesis** is a

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

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

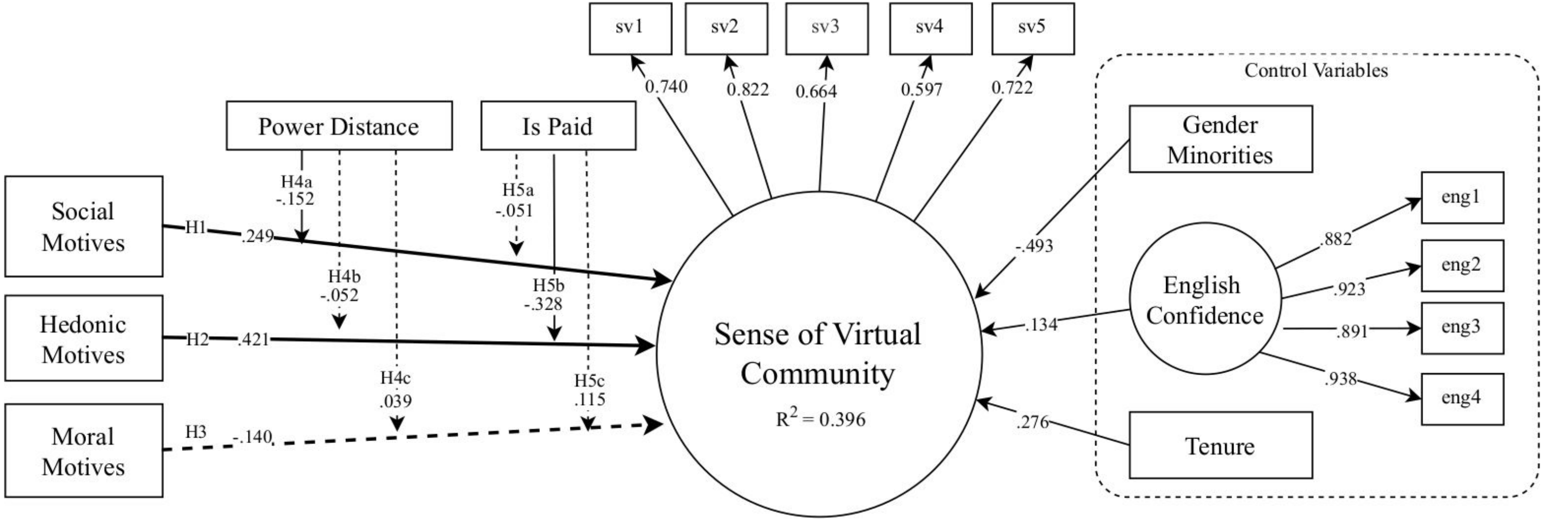
Name	Integral equations	Differential equations
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E} \cdot \mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0} \iiint_{\Omega} \rho \, \mathrm{d}V$	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B}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

[1] See https://en.wikipedia.org/wiki/Maxwell%27s_equations

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)



[1] See Trinkenreich et al. (2023)

Classification of Sciences (by Subject)

Formal Sciences

- Mathematics, …

Takes a formal approach

Takes an empirical approach

Natural Sciences

- Physics, chemistry, biology, …

Social Sciences

- Psychology, sociology, political science, …

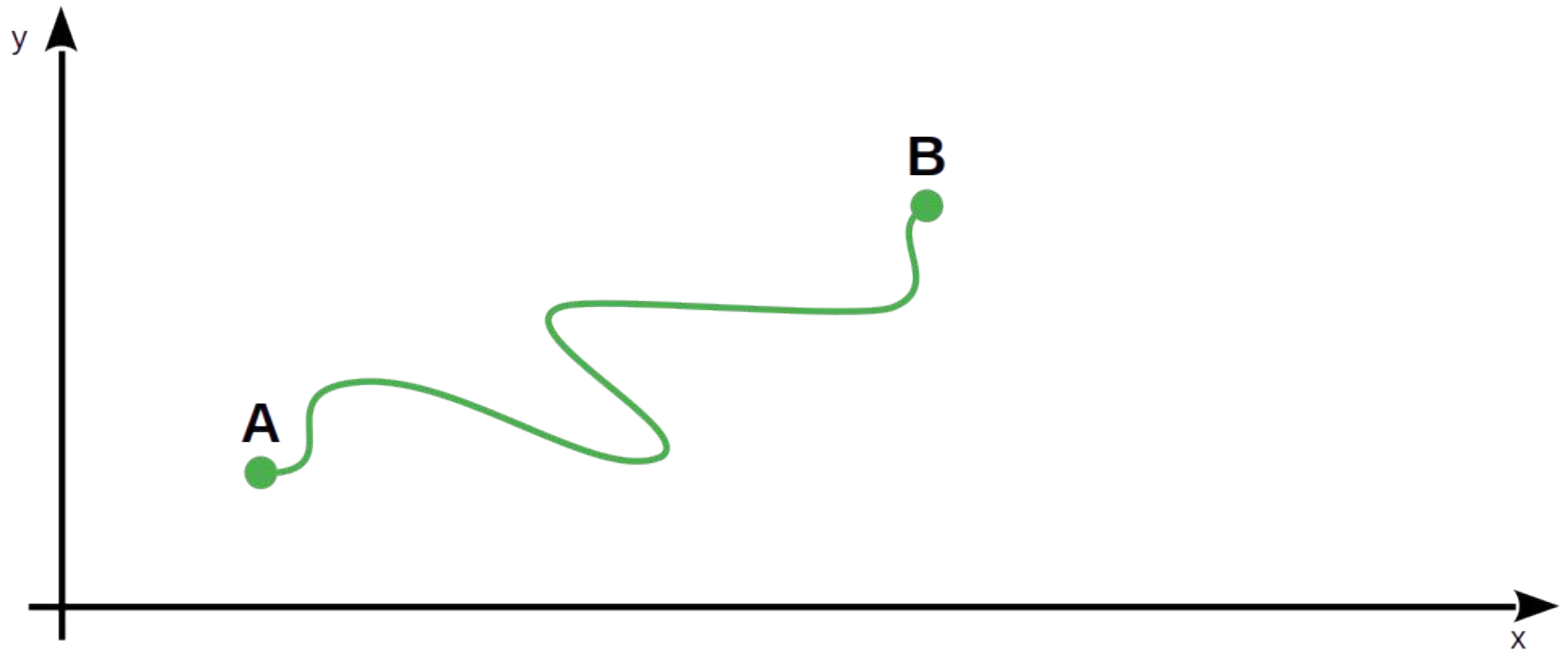
More likely to take an analytical approach

More likely to take a design science approach

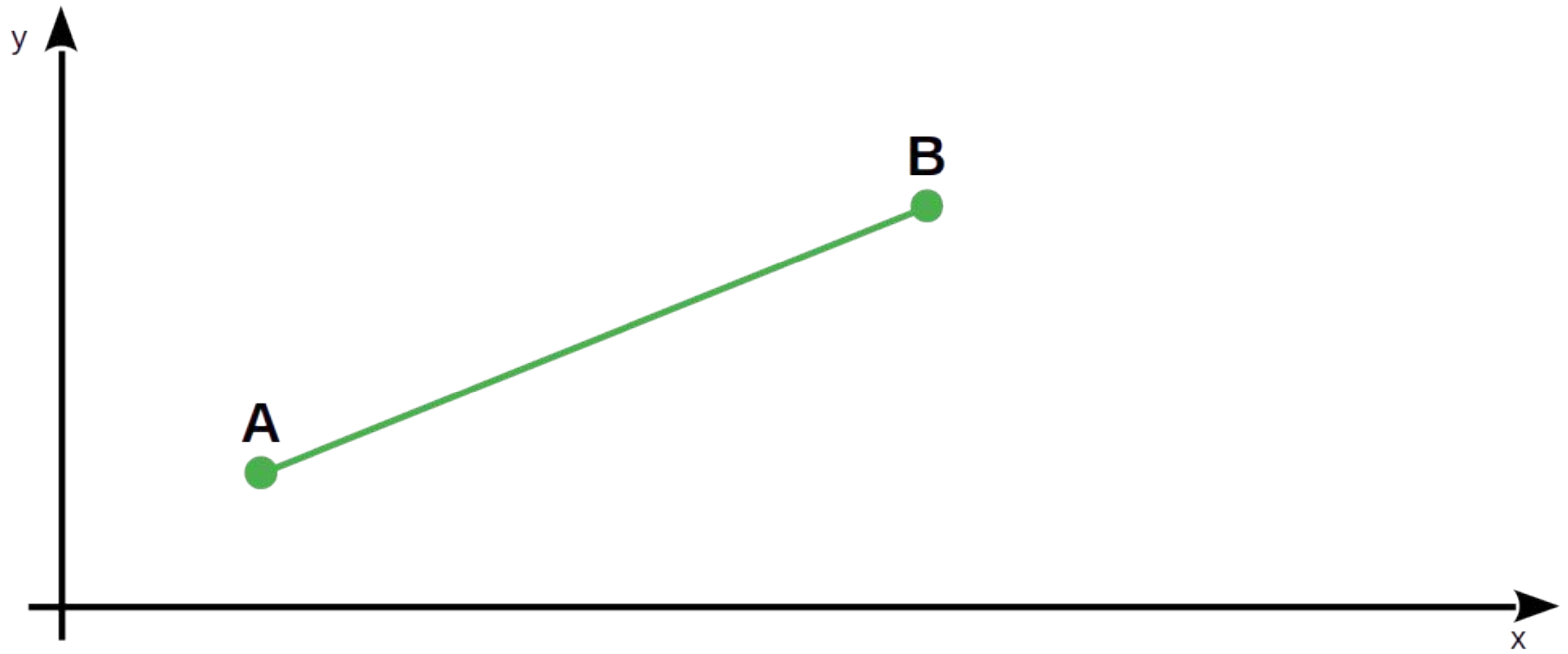
Applied Sciences

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

Solving a Problem vs. Building a Theory



Using a Theory to Solve a Problem



Science vs. Engineering

Science is

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

Engineering is

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

2. Theory Building and Validation

Theory Building and Validation

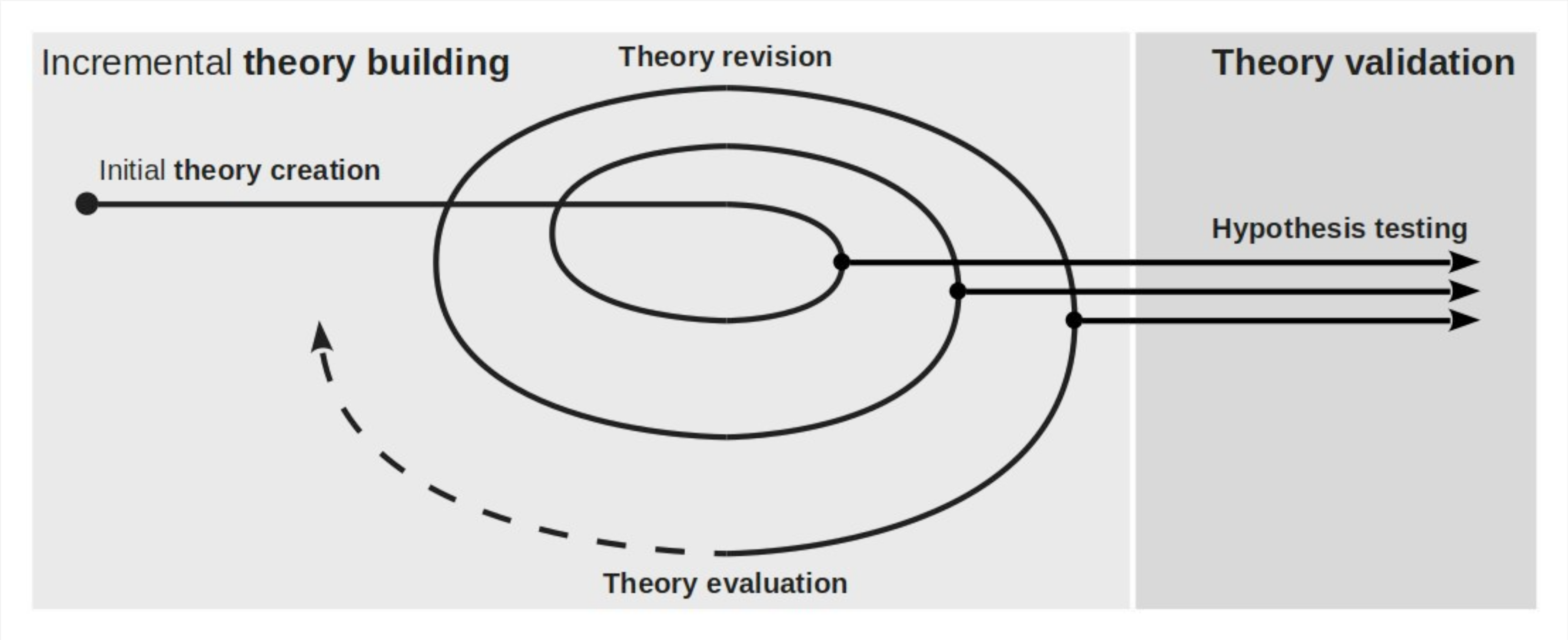
Theory building is

- 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]



[1] Not drawn to scale or effort involved

Theory Evaluation vs. Validation [DR]

Theory evaluation is

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

Theory validation is

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

Many researchers (sloppily) use these terms interchangeably

Exploratory and Confirmatory Research

Exploratory research is

- Theory building research

Confirmatory research is

- Theory validation (testing) research

Inductive vs. Deductive Research

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

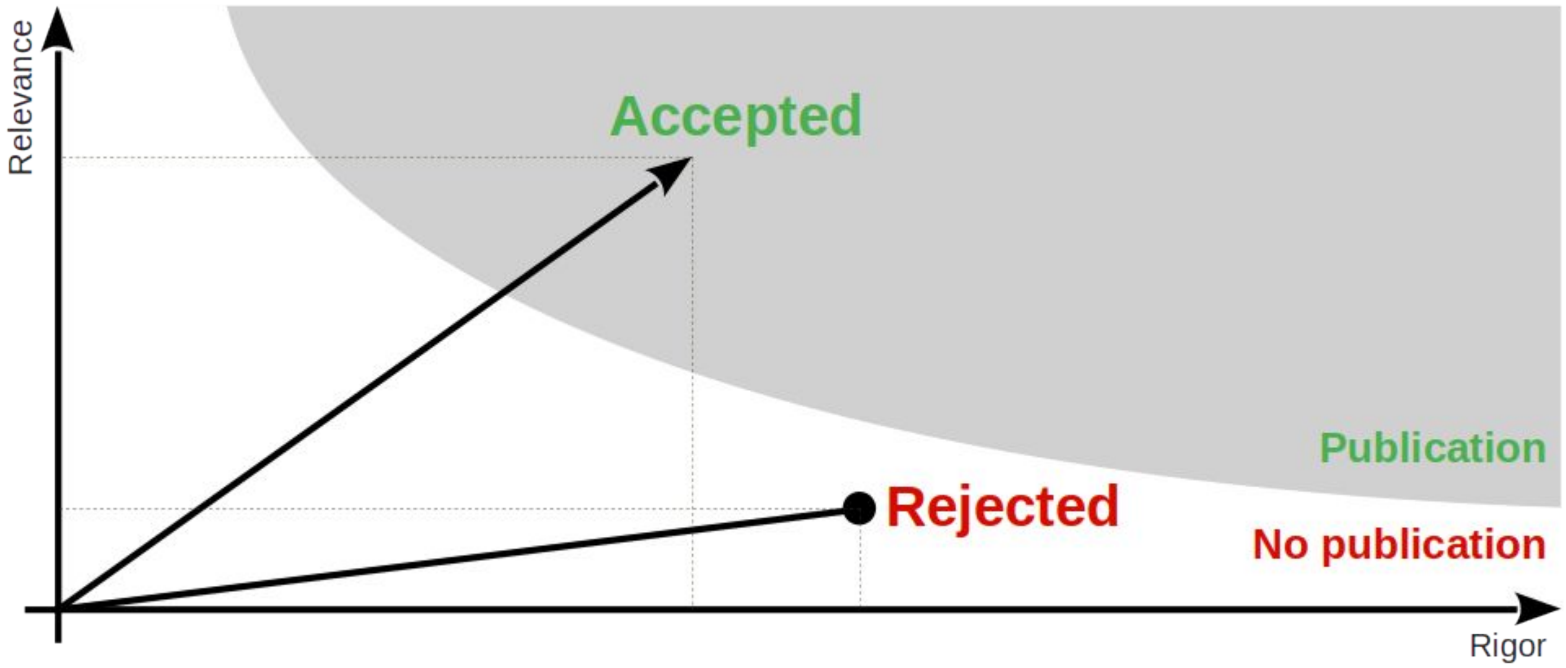
Process of Theory Building and Validation

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

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?

Everyone.

We are all peers.

Some are more peer than others.

4. Programs and Projects

Program and Project Hierarchy

Role	Level	Purpose
Sponsor	Theme	● Defines a research theme ● Funds programs within the theme
Program manager	Program	● Applies for managing a program ● If chosen, manages the program
Principal investigator	Projects	● Applies for a project within a program ● If accepted, carries out the project

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	• Innovation in software engineering
Program	• Improving programmer productivity
Projects	• How to use chat AIs for code generation? • Is static typing superior to dynamic typing?

The Role of Students in Research Projects

Role	Responsibility
Principal investigator	● Overall project
Graduate researcher	● Major component in project
Final thesis student	● Contribution to graduate researcher’s project

5. Science and Society

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

DL

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.

[1] See https://amturing.acm.org/

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

Research, the Researcher, and Ethics

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	Value system	Project obligations	Ethical standards	Laws
Researcher	x	x	x	x
Principal investigator		x	x	x
Project sponsor			x	x
Country				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

[1] See Singer & Vinson (2002)

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

[1] See DFG (1998)

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

[1] See MPG (2009)

Summary

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Thank you! Any questions?

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