

How Science Works

And What Fails the Method

Julian Avila

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Universidad Distrital Francisco José de Caldas

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What is the Scientific Method?

Scientific Method: A Common Misconception

Science is not a linear process.

The common Scientific method is an oversimplification.

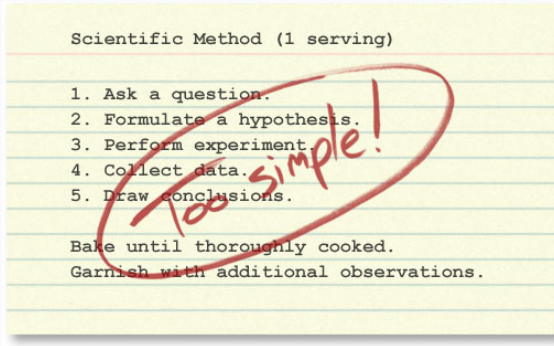


Figure 1: The myth of the step-by-step "science recipe". [1]

How Does Science Actually Work?

Science operates through an iterative, interconnected process:

- **Observation** – Collecting empirical data from experiments or nature.
- **Hypothesis Testing** – Formulating and systematically evaluating explanations.
- **Peer Feedback** – Refining theories through collaboration and critique.
- **Application** – Translating scientific knowledge into real-world innovations.

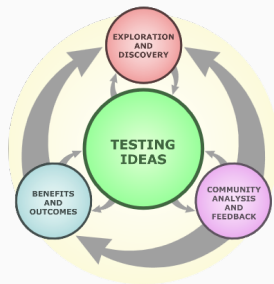


Figure 2: Science as a dynamic, self-correcting process. [1]

The Core of Science: Testing Ideas

Empirical testing is the foundation of science.

Through experimentation and analysis, hypotheses are refined, rejected, or strengthened.

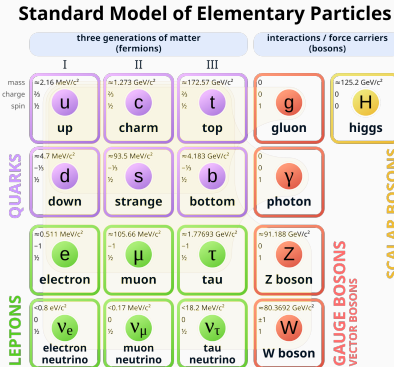


Figure 3: The Standard Model: A theory refined through decades of testing. [2]

Core Principles of the Scientific Method

Observation: Identifying Patterns and Gaps

Processes:

- Reviewing Scientific Literature
- Analysing Known Phenomena
- Examining Existing Data
- Identifying Unsolved Problems

Results & Connections:

- Formulation of New Hypotheses
- Refinement of Existing Questions

Nature of Light

Newton's Idea

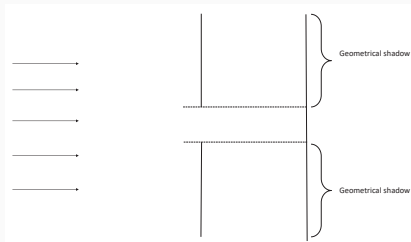


Figure 4: Newton's particle theory of light.

Huygens' Principle

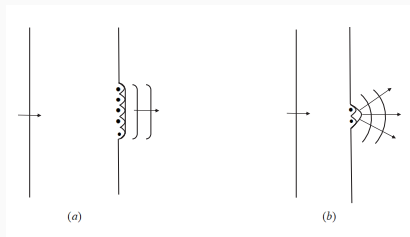


Figure 5: Huygens' wave theory of light.

Observation showed that Newton was mistaken. [3]

Hypothesis Testing: Validating Scientific Claims

Processes:

- Designing and Conducting Experiments
- Collecting and Analyzing Data
- Comparing Results with Predictions

Results & Connections:

- Discovery of New Patterns or Anomalies
- Theory Development or Refinement
- Practical Applications in Technology or Industry

De Broglie hypothesis

Louis De Broglie proposed that particles have associated waves. [4]

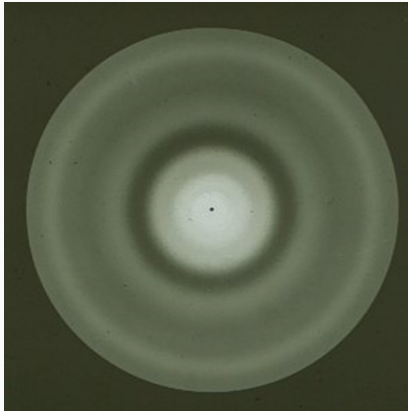


Figure 6: Electron diffraction pattern—evidence of wave behaviour. [5]

Processes:

- Independent Replication of Experiments
- Peer Review and Critical Evaluation
- Scientific Discussions and Debates
- Integration into Theoretical Frameworks

Results & Connections:

- Identification of Errors or Biases
- Generation of New Hypotheses
- Expansion of Scientific Applications

Wave and particle or wave-particle behaviour

The Feedback from theories generated different interpretations. [6]

De Broglie-Bohm Theory

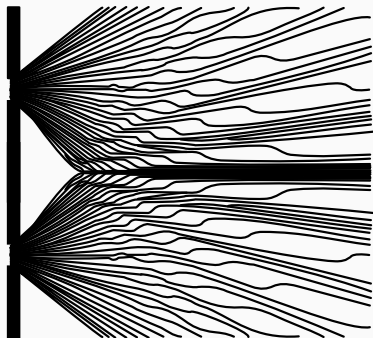


Figure 7: Photon trajectories in the double slit experiment. [7]

Copenhagen Interpretation

$$|\psi(x, t)|^2$$

Probabilistic interpretation of wavefunction collapse.

Processes:

- Development of New Technologies
- Implementation in Medicine, Engineering, and Society
- Identification of Emerging Challenges

Results & Connections:

- New Observations for Future Research
- Inspiration for Novel Experimental Approaches

Wave Nature in Analytical Techniques

Electron diffraction is used to determine crystal structures. [8]

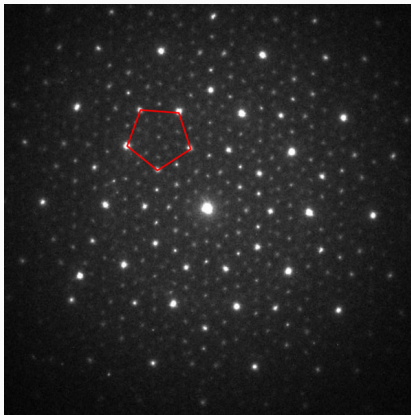


Figure 8: Electron diffraction pattern of a decagonal quasicrystal of Al-Cu-Fe-Cr. [9]

Important Facts

Theories Evolve

Theories are not set in stone—new evidence refines and improves them over time.

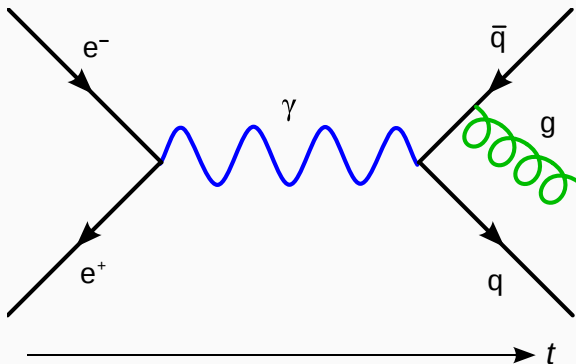


Figure 9: Quantum Field Theory, one of the most successful theories. [10]

The simplest explanation is preferable.

Example: Renormalization in Quantum Field Theory

Instead of introducing an infinite number of parameters, renormalization allows QFT to explain physical phenomena using only a few experimentally determined constants.

The success of the **Standard Model** lies in its parsimony: a limited set of symmetries and fundamental interactions describes a vast array of experimental results.

While it helps ensure better research, peer review has limitations— it can become a barrier to knowledge or create a false sense of quality.

Example: Reinvention of Calculus in 1994

A peer-reviewed medical paper unknowingly reinvented the **trapezoidal rule** for numerical integration, illustrating how errors can persist in published research. [11]

Example: Reinvention of Calculus

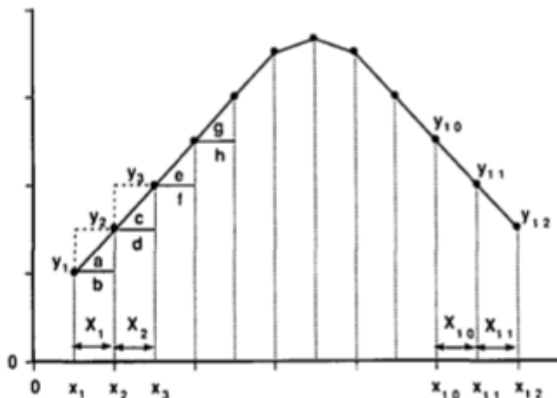


Figure 1—Total area under the curve is the sum of individual areas of triangles a, c, e , and g and rectangles b, d, f , and h .

Conclusions

Science is a dynamic process.

- The scientific method is not a rigid sequence but a network of interconnected processes.
- Theories evolve as new evidence emerges—certainty in science is always provisional.
- Parsimony guides scientific progress by favouring explanations with fewer assumptions.
- Peer review is useful but not infallible; critical thinking remains essential.
- Applications of scientific knowledge drive technological and societal progress.

Science advances by continuously refining ideas through observation, testing, and feedback.

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