Scientific Investigation and Invention

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Nature of Science

- I. Community of science: making use of collective wisdom, encouraging free exchange and open-minded discussion and debate; scientists critically assess new discoveries via the peer-reviewing system

Nature of Science

- II. Attitude of science: searching for truth; science is based on evidence and empirical standards; it also encourages innovation and scepticism

Nature of Science

- III. Practice of science: precise experimental design and proper instrumentation; prudent handling of quantitative and qualitative data; honest reporting

Nature of Science

- IV. Thinking processes of science: scientific knowledge is built on creative thinking; the application of deductive and inductive logic leads to the emergence of new scientific theories, which are then tested empirically; scientific knowledge, while durable, has a tentative character

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Unifying Concepts of Science

- Systems, order, and organization: Systems, order, and organization are ways to observe and describe phenomena that are related to each other and/or work together as a whole.
- E.g. periodic table

Unifying Concepts of Science

- Evidence, models and explanation: Scientists use evidence and models to understand, explain and/or predict scientific phenomena.
- Mathematical model
- Conceptual model: e.g. Einstein's Theory of Relativity
- Biological model: e.g. *E. coli*
- Physical model: DNA model

Unifying Concepts of Science

- Change, constancy, evolution and equilibrium: Change, constancy, evolution and equilibrium all describe states of being of a scientific phenomenon.
- E.g. biological evolution

Unifying Concepts of Science

- Form and function: Form and function are usually interrelated; the function of an object frequently relies on its form.

Major Steps in a Scientific Investigation

Observation

↓

Question

↓

Hypothesis Set

↓

Presuppositions + Evidence → Conclusions

[Archives]

- Presuppositions
  - Science requires several common-sense presuppositions, including that the physical world exists and that our sense perceptions are generally reliable; e.g. if you are not sure if you are real or you are just a dreaming butterfly, no science research can be done
- Archives
  - Irrelevant knowledge

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[Archive]

Making Important Observations is the Essential First Step

- Curiosity (the driving force)
  - Looking for explanations to phenomena of life and Nature

- Sensitivity (do not overlook important clues)
  - E.g The discovery of penicillin
- Comprehensiveness (gather enough information)
  - E.g Darwin’s evolution theory

Major Steps in a Scientific Investigation

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[Archive]

Asking the Right Question

- Organize your observations
- Search for related information in literatures (require basic ability to distinguish valid and invalid information)
- Have this observations previously explained by others?
  - If yes, do you satisfy with the explanation?
- After searching for available information, do you still have an unsolved question? What is it? Write it down.

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Formulating a Hypothesis

- Based on all known and related information, propose a possible explanation (hypothesis)
- The prediction power of a hypothesis determines its validity

Applying Logic in Making and Testing Hypothesis

Observation

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Question

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Hypothesis Set

Deductive logic ↓ / Inductive logic ↺

Presuppositions + Evidence → Conclusions

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- Inductive Logic
  - From actual data to get an inferred model
  - Strong if its premises support the truth of its conclusions to a considerable degree, and is weak otherwise
  - E.g. for 100 living bacteria observed, they all are capable of doubling its DNA content during cell division; conclusion: in all bacteria, they have a mechanism to replicate DNA

- Deductive Logic
  - From a given model to predict expected data
  - The truth of its premises guarantees the truth of its conclusions, and is invalid otherwise
  - E.g. since our model that all bacteria can replicate their DNA, we should expect to see DNA replication in bacteria #101, #102, and etc.

A Hypothesis Can Only Be Disproved

Hypothesis	Prediction
True	True
False	True or False

Examples in Hypothesis Testing

- The nature of light
  - Hypothesis: light is a pure substance that cannot be further separated
  - Prediction: light cannot be separated into different components
  - Actual result: light can be separated into different components using a prism
  - Conclusion: the prediction is false and hence the hypothesis is disproved
  - New hypothesis: light consists of separable components

Examples in Hypothesis Testing

- The phlogiston theory
  - Hypothesis: all flammable materials contain phlogiston, a substance without color, odor, taste, or weight that is liberated in burning
  - Prediction: no gain of weight should be observed after burning of a flammable material
  - Actual result: the combustion product of a metal gained weight
  - Conclusion: the prediction is false and hence the hypothesis is disproved
  - New hypothesis: a flammable material combines with a substance in the air during the combustion process

Examples in Hypothesis Testing

- Theory of Evolution
  - Hypothesis: evolution is driven by inheritance of acquired characters
  - Prediction: if acquired characters can be inherited, when the tails of parent rats are cut, their offsprings should have no tails
  - Actual result: after repeated the tail-cutting process for many generation, the offsprings still had tails
  - Conclusion: the prediction is false and hence the hypothesis is disproved
  - New hypothesis: evolution is driven by natural selection

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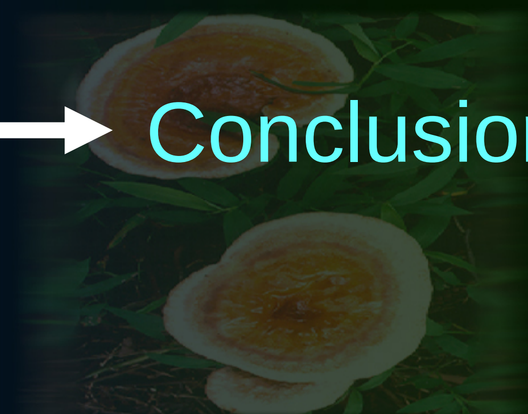

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How to Collect True Evidences (Carefully Designed Experiments and Accurately Recorded Observations)

- Proper instrumentation; e.g. I. Newton decomposes light by using a prism
- Careful experimental design: controls or baseline (i.e. reference points)
- Accuracy of data; e.g. the story of phlogiston, oxygen and Antoine Laurent Lavoisier
- How to handle quantitative data (errors occur by chance): statistics; e.g. if your hypothesis is that "man is taller than woman", it may not be always true (but can you generalize?)

Scientific Invention: Determining an Objective

- Types: products, processes, technologies
- Needs and Added Values: New functions? Faster? More efficient? Easier? or Cheaper? (A survey of existing products, processes, and technologies may be useful)
- Novelty (Innovation): Brand new ideas? Improvement/modification of existing ones?
- Feasibility: availability of essential raw materials, scientific knowledge, manpower, and venture capital
- Commercial potential: identification of end users, assessment of market scale, etc.
- Social and ethical issues: is this invention beneficial to humanity

Scientific Invention: Making a Design

- What kind of design can fit to your objective?
- What is the scientific base of your design?
- How to test (experimental design) if your design will fulfill your objective?
- Applying the same principles (nature and unifying concepts of science), logics (inductive and deductive), and methodology of data analysis (qualitative and quantitative) of scientific investigations.

Scientific Invention: Building and Testing a Prototype

- Build a physical model/miniature of your invention; show its function by physical demonstration
- Illustrate by animation and extrapolation, using previously tested and hypothetical data
- Does you invention really perform as you predict? (i.e. is the result consistent with your hypothesis)
- Any improvement/modification needed? (i.e. revision of hypothesis)
- Or an unexpected function is achieved?

References

- “Hypothesis, Prediction, and Implication in Biology” by J.J.W. Baker and G.A. Allen
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- “Inquiry and the National Science Education Standards: A Guide for Teaching and Learning” published by National (USA) Academy of Sciences