Scientific Method

Gaining the confidence

Scientific Method

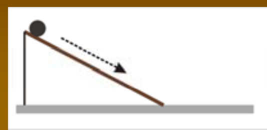
- How scientific discoveries are verified (and therefore become "discoveries").
- The basis of confidence in hypotheses, supporting claims of knowledge.

Types of Logical Reasoning

- Induction:
  - The forming of general statements from a number of particulars.
- Deduction:
  - The forming of statements (assertions) based on logical necessity.
    - A deduction can be a specific statement or a general conclusion.

The empirical vs. the non-empirical sciences

- Empirical sciences
  - General statements are formed from inductions and then used to deduce consequences.
- All sciences of the natural world are empirical sciences.



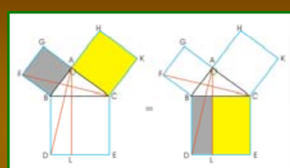
Example: Galileo's Law of Falling Bodies:

$d = 4.9\text{m} \times t^2$

Based upon measurements of actual bodies falling, or rolling, then generalized.

The empirical vs. the non-empirical sciences

- Non-empirical sciences
  - Start with axioms and deduce all consequences.
  - No reference to experience or observation.
- Examples: logic and mathematics.

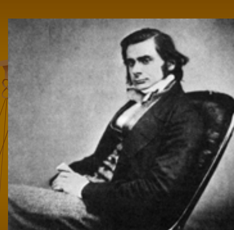


Example: Euclid's Proposition I.47 (The Pythagorean Theorem).

The conclusions depend only on the axioms and the validity of the logic that deduced them.

The Common Sense View of Science

- Thomas Henry Huxley, prominent 19th century British biologist, took the view that science is really just a refinement of ordinary common sense.
  - Huxley made many speeches to non-scientists explaining (and de-mystifying) science.



Night school


SCHOOL OF ARTS
FOR THE
Instruction of Mechanics, &c.
LIBRARY ROOMS, No. 2, DRUMMOND STREET.

- In Britain after the invention of indoor gas lighting in the 19th century, educational institutions sprang up offering lectures and night courses for working people.

The Mechanics Institutes

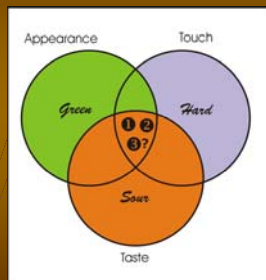
- The best known were the Mechanics Institutes, where many educational leaders came to give public lectures.

Huxley at the Mechanics Institutes

- At one, Huxley explained how scientific reasoning was just common sense. His illustrative examples follow….

Huxley's apples: Explaining induction

- Suppose, says Huxley, that one goes to buy an apple and is handed one that is green. It also feels hard. On biting into it, it tastes sour.
- After repeating the same experience a number of times, one might reasonably conclude that ALL green, hard apples are sour.



The principle of induction

- After noting several instances of essentially the same circumstances, always followed by the same result, we naturally form the general conclusion that those circumstances are always followed by that result.
- This, says Huxley, is a commonplace of everyday life and is how we learn to live in the world.

Induction leads to possible deductions

- The person who suffered several green, hard apples that proved to be sour then learns a lesson and avoids green, hard apples in the future.
- That is, armed with the induction, it can be used as a premise in a deductive logical argument.

The reasoning that avoids the next sour apple

- A syllogism:
  - Major premise:
    - All green and hard apples are sour.
  - Minor premise:
    - *This* apple before me is green and hard.
  - Conclusion:
    - This apple is sour.
- This, says Huxley, is the general form of of the scientific method.

SC/NATS 1730, XXI 13

Choosing among different hypotheses

- Preferring the probable and the consistent
  - When several hypotheses can each account for the phenomena, the most probably one, or the one most consistent with other phenomena is to be favoured.
  - This is known as the principle of *parsimony*, choosing the simplest explanation that covers the evidence.
    - Known also as Ockham's Razor – introduced by William of Ockham in the 14^{th} century.

SC/NATS 1730, XXI 14

Huxley's homey example

- On waking in the morning and coming downstairs, one finds the teapot and silverware missing, the window open, a dirty hand on the window frame, footprints in the gravel outside....
  - Many explanations are possible, but the evidence points strongly to a thief. This would be the reasonable conclusion.
- In general *ad hoc* explanations are to be avoided.

SC/NATS 1730, XXI 15

Ad hoc hypotheses

- *Ad hoc* hypotheses are invented to fit the circumstances of the particular phenomenon to be explained. Unless they seem probable or are consistent with other phenomena (that appear independent of the case at hand), such hypotheses have little value.
- It is always possible to come up with an *ad hoc* explanation for any phenomenon.

Examples of *ad hoc* arguments

- Huxley's missing teapot and silverware:
  - The argument that supernatural causes were responsible for the disappearances, e.g. that the teapot flew out of the window on its own accord, etc.
- Copernicus' explanation of why Venus did not show phases:
  - He said Venus had its own light, like the Sun.
- Simplicus' last ditch argument against the Copernican world view:
  - That God could make the heavens do whatever He pleased.

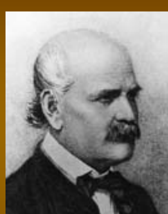
The downside of the common sense view

- While Huxley's analysis covers many situations, science often comes to conclusions that are very much *not* common sense.
  - E.g., that the Earth is spinning around every day and hurtling through space around the sun.
  - E.g., universal gravitation – that every body that has mass attracts every other body that has mass with a force proportional to the product of their masses and inversely proportional to the square of the distance between them.

Testing Hypotheses

- When an explanatory idea about nature is proposed, it remains a conjecture until it is verified one way or another.
- One of the key features of scientific method is systematic testing of hypotheses.

Case study: Puerperal Fever



- A young obstetrician, Ignaz Semmelweis, working at the Vienna General Hospital in 1844-1848 was concerned about the high incidence of death from puerperal fever in his patients and sought to understand its cause.

Puerperal fever

- Puerperal fever, also called childbed fever, is a virulent disease that attacks women shortly after childbirth, generally resulting is death in a few days.
- Its causes were unknown. Its incidence at Vienna General were especially high.

General facts about pueperal fever in the Vienna General Hospital

- There were two maternity divisions, the First, run by doctors, the Second, by midwives. Each had students working with them.
  - The death rate from puerperal fever was much higher in the First Division than in the Second.
- "Street births," women who gave birth en route to the hospital general escaped getting the fever.

Semmelweis sought all possible explanations

- Semmelweis looked for every possible explanation why the fever should be higher in his ward and sought to eliminate them one by one.
  - Other than doctors versus midwives, there were few differences in diet or general care between the divisions.

Focusing on the differences that there were

- The differences that could be identified included:
  - Priests coming to deliver the last rites to the dying women were accompanied by an attendant ringing a bell. In the First Division, the priest walked through the wards to get to the patient. In the Second Division, priests used a side door and did not go through the wards.

Other differences noted:

- Windows in the First Division opened out to the street. Those in the Second Division opened into an inner hallway.
- In the First Division, women delivered babies on their backs. In the Second Division, the turned on their sides.

A built-in control group

- Semmelweis sought to eliminate possible causes by changing practices in the First Division to match those in the Second.
  - He changed the access route of the priests delivering last rites and eliminated the bell.
  - He closed the windows to the outside.
  - He had women in the First Division deliver babies on their sides.

Eliminating hypotheses through *modus tollens*

- The logical principle that Semmelweis employed has the name *modus tollens.*
- *Modus tollens* is a form of the syllogism that demonstrates that the major premise is inconsistent with the minor premise.
  - If the minor premise is known to be true, then the major premise must be false.

Modus tollens as a tool in empirical science

- *Modus tollens* is the essential logical tool to eliminate errors in empirical science.
  - If the major premise is an explanatory hypothesis and the minor premise is a set of observed facts, *modus tollens* can be used to show that the hypothesis must be false and therefore must be discarded.

Semmelweis and *modus tollens*

- Semmelweis showed that changing the routine of the priests made no difference to the puerperal fever rate.
  - Neither did closing the windows, nor having women deliver on their sides.
- Since none of these made any difference, these were not the causes.

The *modus tollens* syllogism

- Call the hypothesis *H.*
- The hypothesis will have an observable implication, *I.*
- Major premise:
  - If *H* is true, then so is *I.*
- Minor premise (the observation):
  - *I* is false.
- Conclusion:
  - *H* is false.

A key point

- *Modus tollens* is only useful for *eliminating* a hypothesis.
  - The proposed explanation *H* implies that the observable fact *I* will be true.
  - If *I* is not true (e.g. the puerperal fever rate did not go down), then something is wrong with the explanation.
- But if *I* is true, the hypothesis is not proven.

New evidence for Semmelweis

- After coming up empty handed on finding the cause of the fever, a freak accident gave Semmelweis a new idea.
  - His colleague, Kolletschka, died in a few days after receiving a puncture wound from a scalpel while doing an autopsy. Kolletschka displayed symptoms similar to puerperal fever during his brief illness.

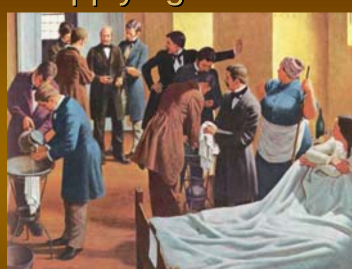
Cadaveric matter

- Semmelweis hypothesized that Kolletschka was killed by the “cadaveric matter” introduced into his body by the scalpel, and that perhaps his female patients are similarly infected by “cadaveric matter” when being examined by medical students who have come from doing autopsies.
- Semmelweis formulates a new hypothesis and a test for its validity.

The hypothesis and its test implication

- Hypothesis:
  - *H* = Cadaveric matter entering the bodies of women induce puerperal fever.
- Test implication:
  - *I* = If medical students wash their hands thoroughly in a solution of chlorinated lime to remove all traces of cadaveric matter before examining women in the maternity ward, incidences of puerperal fever will drop off dramatically.

Applying the test



- Semmelweis ordered medical students and doctors to use the chlorinated lime solution when coming from the autopsy room.

Interpreting the test

- The incidence of puerperal fever in the First Division promptly fell to a rate lower than that of the Second Division.
- Eureka?

Further confirmation

- Later, when his instructions were not followed, the incidence rose again, but was halted when washing with chlorinated line was resumed.
- Semmelweis believed he had found the cause of the disease.
- Was he justified in believing so?

SC/NATS 1730, XXI 37

The Error of Semmelweis

- Semmelweis believed that cadaveric matter (i.e., bits of corpses) was the *only* cause of puerperal fever.
- His reasoning:
  - Bits of dead bodies cause the infection. Eliminate the cadaveric matter → no infection.

SC/NATS 1730, XXI 38

A troubling unexpected case

- A woman had been admitted with cervical cancer and had been placed in the maternity ward.
- She had been examined by the doctors and students, who then went on to examine the other women in the ward, without washing their hands.
- *All* the other women in the ward developed puerperal fever.

SC/NATS 1730, XXI 39

The hypothesis, *H*, was too restrictive

- Semmelweis had believed that only matter from corpses conveyed the infection. He had not considered that the problem was putrefaction.
  - There was no theory of microbes at the time. Disease was not understood to be caused by bacterial infection, since bacteria were basically unknown.

SC/NATS 1730, XXI 40

The Fallacy of Affirming the Consequent

- Semmelweis had unwittingly committed a logical fallacy, known as the *fallacy of affirming the consequent.*
- The form of the fallacy:
  - If *H* is true, then so is *I*.
  - *I* is true.
  - False conclusion: *H* is true.

SC/NATS 1730, XXI 41

Semmelweis' fallacy

- His implication, *I* , was that washing the hands after doing autopsies will prevent the fever.
- His hypothesis, *H*, was that cadaveric matter was the sole cause of the fever.
- But the reasoning is fallacious because *I* can be true when *H* is false.
  - E.g., apples that are not green and hard can also be sour.

SC/NATS 1730, XXI 42

Falsification

- It is an inescapable feature of empirical science that a hypothesis, or a theory, can *never* be fully verified as true.
- It *is* possible to show that a hypothesis is false (using *modus tollens*), but not to be true.

SC/NATS 1730, XXI 43

Confirmation

- The best that can be done is to confirm that a hypothesis is consistent with other hypotheses and theories, and has many true implications, and therefore, probably, is true as far as we know.
- The logical form of confirmation:
  - If H is true, then so are I_1, I_2, I_3, ..., I_n.
  - Evidence shows that I_1, I_2, I_3, ..., I_n are all true.
  - Conclusion: H is probably true.

SC/NATS 1730, XXI 44