# SCIENCE

Lecture 1: The Scientific Method and its Accompanying Problems

# Overview

The Scientific Method

Problems with Observation

Problems with Testing Hypotheses

# The Problem of Demarcation

- Context: Science enjoys much respect today because of the great boon it has been for society
- To the point where if there are two or more rival claims, then we are more likely to believe the one that is scientifically based (whether this is justified or not is open for debate)
- i.e. we tend to privilege Science over any other body of knowledge
- E.g. Religion (existence of God), Philosophy (metaphysics – what is real and what isn't), Literature (insight into the human psyche)
- Many have thus claimed that their claims are "based on science"
- So we have to be able to decide what is scientific and what is not
- This is the Problem of Demarcation
- One of the most common and intuitive ways to do this is to ask if a certain claim has been arrived at/constructed by the Scientific Method

# Why does the pen fall when it is let go of from a height?

# Hypothetico-Deductive Method

| Method | Example |
| --- | --- |
| 1. Science begins with an interesting **observation** | The pen drops when let go of from a height |
| 2. Observation leads to a **hypothesis** (via <u>inductive</u> reasoning) | "There must be a force (gravity) working on all things that pull them downwards." |
| 3. Hypothesis allows us to make a **prediction** (via <u>deductive</u> reasoning) and to then design an **experiment** to test it | Prediction: "Any other item when let go of from a height will also fall." Experiment: Drop multiple items from a height |
| 4. After many instances of corroboration via the experiments, the hypothesis is verified and gains the status of a law (otherwise, it is falsified) | Gravity pulls things downwards towards the center of the Earth |
| 5. Eventually, the law is worked into a theory which unifies various other laws | Newtonian Mechanics |

# Another Example

- Observation: Ptolemy's model of planetary motions is too complicated
- Hypothesis: Sun as the centre of the solar system, Earth revolves around it
- Experiment/ Prediction: Venus should seem to vary in size *to us* if Copernicus is right; not so if Ptolemy is right
- Law: Kepler's laws of planetary motions
- Theory which unifies and explains various laws: Newtonian Mechanics

# Other Key Features

- A good experiment should also have:
- 1) Measurability of Variables: these allow for precision and objectivity (non-biasedness)
- E.g. Counting the instances of things falling to the ground when let go of from a height
- 2) Controllability of Variables: you should be able to vary only one factor at a time so that you can determine its effect
- E.g. Changing the objects being dropped while keeping the environment constant, or testing a range of environments with a standardised set of objects
- 3) Repeatability: with controllability, your experiment can now be repeated by *other* people so that they can check and confirm your results – again, objectivity
- E.g. Other people letting go of things from a height across the Earth

# Preliminary Comments

- Imagination plays a key role and can even go against our intuition as well as what our senses tell us (e.g. Copernican revolution – the Earth moves instead of the Sun)
- Technology extends our powers of observation which then helps us to develop better justified scientific theories (e.g. Galileo was only able to detect the change in the apparent size of Venus with the use of a telescope – this allowed him to verify his hypothesis while falsifying Ptolemy's)
- Anomalies are an important part of science – they help us to develop better theories (e.g. Galileo looking through the telescope and realising that contrary to Ptolemy's prediction, Venus *does* vary in size in its orbit)

# Problems

- Given the huge importance and utility of science today, it would seem that the Scientific Method is the high water-mark of knowledge construction and that it can do no wrong
- But there are problems for the SM and this can be broken down to its various stages:
- Problems with Observation
- Problems with Testing Hypotheses

# Problems with Observation

- A.k.a. the Data gathering Stage
- **Relevance** – There is always an infinite number of possible variables to observe at any one time.
- Yet in order to do science, we need to be able to determine which variable is relevant and which isn't.
- Otherwise, we can never get down to actually doing the experiment
- Not to mention that it is physically impossible to observe every possible variable at any one time
- But how to decide? Are our decisions merely another form of bias?

# Example

- Question: Why do some students catch a cold in winter and some don't?
- Some possible factors include: Diet, Exercise, Domestic Heating, Warmth of Clothing, Colour of Underwear, One's middle name, and the movies one watched
- Which of these variable are relevant and which are not?
- Obviously, few if any would think that the colour of your underwear doesn't affect the experiment - but what if it does?
- Less facetiously, in a chemistry experiment, we often do not count how many people there are in a room
- Yet the number of people can affect the temperature of the room which in turn could affect the speed of the chemical reaction, especially in a sensitive experiment
- Our ideas of what counts as relevant or not could thus be based on our own preconceived notions which are biased.
- This thus affects the objectivity of Science

# Problems with Observation

- **Expectations** – our expectations can influence what we see
- Recall the problem of corrigibility in empiricism – our background beliefs can influence what we observe such that we ‘see’ things that are not actually there
- E.g. scientists seeing ‘little sperm men’
- In other words. Instead of observation being objective and theory-neutral, they could well be influenced by our background beliefs and the theories that we hold such that observations are theory-laden instead (more on this later)
- Another e.g.: When Mercury was found to be deviating from its predicted orbit according to Newton’s laws, astronomers suggested that the anomaly was caused by an undiscovered planet, Vulcan. They were so convinced by their theory that they thought that they actually saw it through the telescope. But Vulcan doesn’t exist. Mercury’s deviation was only explained by Einstein’s theory of relativity later on.

# Problems with Observation

- **Expert seeing** – we use scientific equipment (e.g. microscopes, telescopes etc) to make observations and deem them to be better than those we make with ‘the naked eye’.
- But only experts who have been trained to use this equipment can verify or falsify the claim; not everyone can do it.
- But why trust them? What if the experts were wrong? (think previous point)
- E.g.: Galileo’s telescope was a fairly crude instrument and his drawings of the moon are quite inaccurate, including some craters and mountains that do not in fact exist

# Problems with Observation

- **Observer Effect** – the act of observation can sometimes <u>affect what we observe</u>
- E.g. To measure the temperature of a cup of water, we insert a thermometer into the cup
- But this act of inserting the thermometer affects the temperature of that which it is measuring
- Of course, this doesn't typically make a significant difference in temperature but in…
- Quantum Physics: the act of observing affects the observed reality
- In fact, the greater the number of observers, the greater the observers' influence on what actually takes place
- E.g. of observing a beam of electrons and how they behave when passing through a barrier
- When there is an observer, the electrons are forced to behave like particles and not like waves (they will only pass through one opening instead of several simultaneously)
- The opposite happens when there is no observer – the electrons behave like waves and can simultaneously pass through several openings in a barrier and then meet again at the other side of the barrier

# Problems with Testing Hypotheses

- A.k.a. the Data Interpretation Stage
- **Confirmation Bias** – we tend to look for verifying results, not falsifying ones (contrary to what Popper thought).
- Explains why we're more likely to dismiss a falsifying result as experimental error or anomaly.
- But why call these an experimental error or an anomaly instead of a falsifying result?
- Suggests a bias against falsifying results and towards established theories
- E.g. Gregor Mendel's work on the hereditary traits of peas (which laid the foundations for modern genetics) had results which were just too good to be believable

# Problems with Testing Hypotheses

- **Underdetermination** – where evidence underdetermines our response, be it in choosing one theory over another in the face of confirming results (contrastive) or whether we should jettison a theory in the face of falsifying results (holistic).
- The main problem for Science here is that evidence is supposed to be the **objective arbiter** for our choices.
- Yet Underdetermination shows that this is merely an ideal that is impossible to achieve.

# Contrastive Underdetermination

- Contrastive underdetermination is the possibility that for any body of evidence **confirming** a theory, there might well be *other theories* that are also well confirmed by that very same body of evidence (recall graph e.g.)
- Hence, evidence <u>by itself</u> cannot determine our theory choice
- Rather, we need to appeal to other criteria like simplicity, comprehensiveness, predictive power, fecundity (i.e. ability to give rise to other theories), precision, or even familiarity
- Each criterion has its fair share of proponents and it's not clear that any one criterion should be privileged over the others (a Kuhnian would say that these represent the incommensurability of standards thesis)
- CU happens when we are choosing between rival theories for a particular phenomenon

# Example

- Consider Newton's cosmology, with its laws of motion and gravitational attraction.
- As Newton himself realized, <u>exactly the same predictions</u> are made by the theory whether we assume that the entire universe is at rest or that it is moving with some constant velocity in any given direction: from our position within it, we have no way to detect constant, absolute motion by the universe as a whole.
- Thus, we are here faced with **empirically equivalent** scientific theories: Newtonian mechanics and gravitation conjoined <u>either</u> with the fundamental assumption that the universe is at absolute rest (as Newton himself believed), <u>or</u> with any one of an infinite variety of alternative assumptions about the constant velocity with which the universe is moving in some particular direction.
- All of these theories make **all and only the same empirical predictions**, so no evidence will ever permit us to decide between them on empirical grounds.

# Holist Underdetermination

- It is impossible to test a hypothesis **in isolation** because a single scientific hypothesis does not by itself carry any implications about what we should expect to observe in nature;
- Rather, we can derive empirical consequences from an hypothesis <u>only</u> when it is **conjoined** with many other beliefs and hypotheses, including background assumptions about the world, beliefs about how measuring instruments operate, further hypotheses about the interactions between objects in the original hypothesis' field of study and the surrounding environment, etc. (for Kuhn, these background assumptions together with the hypothesis make up the paradigm, not the hypothesis alone)
- For this reason, Duhem argues, when an empirical prediction turns out to be **falsified**, we do not know whether the fault lies with the hypothesis we originally sought to test **or** with one of the many other beliefs and hypotheses that were also needed and used to generate the failed prediction.
- In other words, evidence <u>by itself</u> doesn't determine our response. What we choose to do next is dependent on other factors like how conservative we are towards scientific theories (i.e. how willing are we to let go of an existing theory/paradigm)
- HU happens when we are choosing what to do in the face of a falsifying result – jettison the theory or add an ad-hoc modification to save it

# Example

- Newtonian mechanics and Neptune
  - Newton's gravitational theory made predictions about the paths of planets as they orbit the sun - mostly verified to be true
  - But Uranus' orbit consistently differed from what Newton's theory predicted
  - By Popper's Falsificationism, this meant that Newton's theory should be jettisoned
  - Yet what happened was that Adam and Leverrier decided to question a background assumption (that there was only 7 planets) and generated an ad hoc hypothesis of there being an 8th planet instead
  - Using Newton's theory, they then were able to calculate the mass and position that this planet would have, and shortly afterwards, they discovered Neptune.
  - But when scientists decided to use this approach to explain Mercury's deviation in orbit and postulated the existence of Vulcan, they couldn't find Vulcan
- Still, how do we know that actually, our instruments are just not good enough to observe Vulcan? Or that there is not another background assumption in Newtonian mechanics that was wrong and that rectifying it would be enough to 'rescue' it?
- Hence, there cannot be any such thing as a **"crucial experiment"**: a single experiment whose outcome is predicted differently by two competing theories and which therefore serves to definitively confirm one and refute the other.
- E.g. choosing to jettison Newton's mechanics or take up Einstein's relativity

# Problems with Testing Hypotheses - the Problem of Induction

- Science verifies its hypotheses via a limited number of experiments
- These results are then **generalised** to become a law of nature that supposedly applies to *all* times and *all* places
- E.g. all metals expand when heated
- This move from <u>particular</u> results to <u>general</u> rule is the **inductive** move
- But as seen before, the problem is that even well-confirmed generalisations can turn out later to be wrong
- E.g. “all swans are white” was believed to be true until the 18th C
- Hume pointed out that the inductive inference from a limited sample of some As that are Bs to “All As are Bs” is valid if and only if we add the uniformity of nature principle, i.e. “the future will resemble the past”.
- Yet this principle is itself the result of an inductive inference – we generalised from past instances of the future resembling the past to this principle.
- In other words, the inductive inference is **question-begging**; it already assumes what it seeks out to prove, i.e. that the future will resemble the past.

# Homework

- Article A (Optional)
- Science Notes pp2.-5 (Articles 1 and 2)
- TOK (224-235)