HSI1000 How Science Works, Why Science Works

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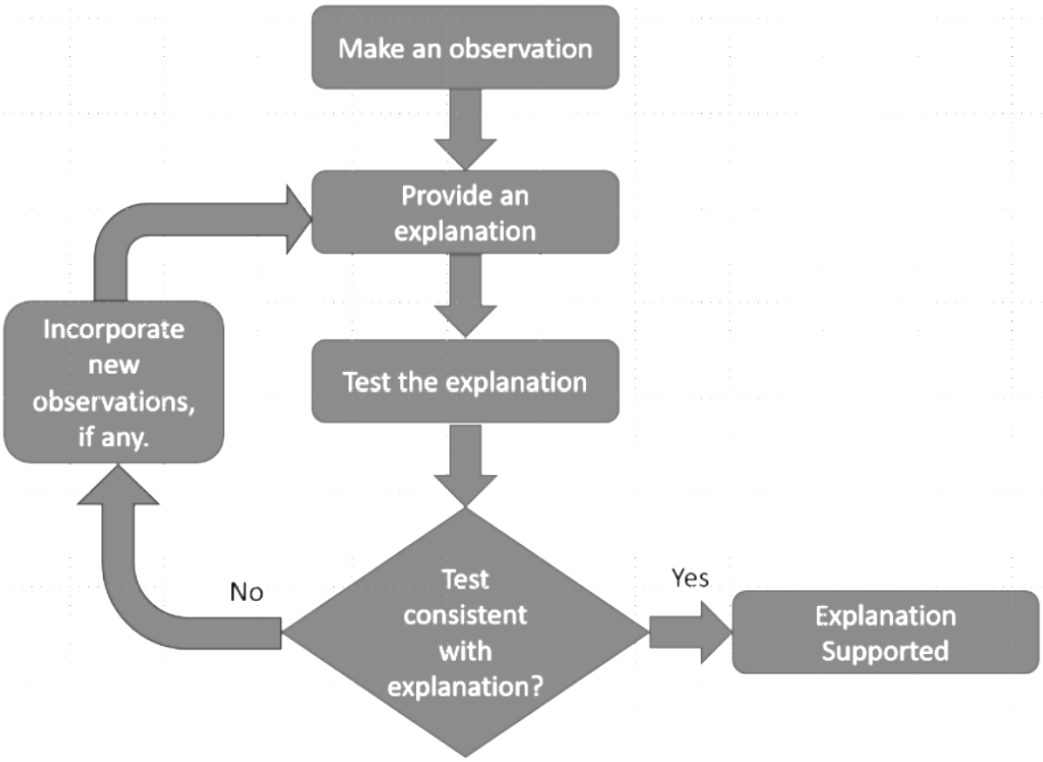
1 The Founding of Modern Science

1.1 What is Science

- **Science**: An activity that aims to further our understanding of why things happen as they do in the natural world. It accomplishes this goal by applications of the scientific method.
- **Scientific method**: 1. Observe 2. Explain 3. Test
- Science is **self-correcting**: multiple wrong explanations proposed and then discarded until arriving at the current version
- Scientific method can be used to probe and discover new things about nature, this relies on our explanation and then testing these explanations

  If these explanation is not falsified, then we have confirmed our explanation (the more we test, the more confidence we have in our explanation)



1.2 Observation

- Roles of observation in scientific inquiry:
  - Identify and focus on **relevant facts** about the phenomenon under investigation
  - Provide **clues to possible explanations** to the phenomenon
  - Provide **evidence** which can prove if various explanation succeed or fail (testing the explanation)
- Concerns that should be addressed when making observations:
  - Do we have a clear sense of what the **relevant phenomena** are?
  - Ensured that we have **not overlooked** anything when making observations?
  - Do we know for sure what is based on **fact** and what is based on **conjecture and assumptions**?
  - Have our observations been contaminated by **expectations or belief**? (Any biases)
  - Have we considered any necessary **comparative information**?

1.3 The Scientific Revolution

- **Based on authority**:
  - There is an accepted idea about how and why things happen in our nature world → cannot be challenged
  - People fearful → did not challenge "norms", accepted them blindly
- **Evidence-based**:
  - Use scientific method to explain phenomena → put aside past beliefs and biases to observe and test their explanations of certain events
  - New instruments: make observations that was not previously possible → anomalies that cannot be explained using current understanding → new explanations and perhaps a new understanding
  - **Scientific community**: individuals may be blinded by own expectation or beliefs → need community to check, cross-check, closely examine individual work (**peer-review**)
- **Anomalous phenomena**: too many anomalies that scientist cannot explain → lose confidence in their own beliefs and explanations → critical of the current understanding → new ideas
- **Scientific revolution**: occurs when scientific community accepts/embraces new theories, concepts and methods brought about by anomalies and abandons old ideas

1.4 The Industrial Revolution

Industrial revolution: great technological innovations changed the world, from one that relies on muscle power to one that now relies on more efficient and effective machines

- **Steam engine** Contribution: Good
  - Increased **production** of item/goods (iron, textile)
  - Provided **employment opportunities** to operate the machine, in city areas (city populations increased) $\rightarrow$ increased average income and standard of living
  - Facilitated **coal mining** (by pumping out water as the mine gets deeper) to power steam engines
  - Improved efficiency of **transporting** material, goods and service via trains and ships
  - Improved **agricultural yield**, greatly reduce famine
  - **Mortality rate** dropped $\rightarrow$ food now more accessible and better sanitation
- Contributions: bad
  - Led to **increased pollution** due to burning of fossil fuels
  - Led to **spread of disease** due to lack of knowledge of germs and hence hygiene
- Impact on population growth:
  - Mortality rate drop, lead to rapid rise in world population
  - Incredible surge in 20th century
- Other implications:
  - Led to **climate crisis** (global warming) $\rightarrow$ increasing population but ever reliant on fossil fuel for energy and provision of goods
  - Loss in biodiversity

2 Baloney Detection Toolkit

Baloney Detection Toolkit (BDTK): establish whether something is true

2.1 Before Applying the BDTK

1. Possess a **sceptical mindset**
    - Scientific explanation: can be falsified
    - Speculation: cannot be falsified
2. Be aware of our **biases**
    - **Confirmation bias**: favour information that confirms one's existing beliefs or values → ignore information contrary to desired outcome
    - **Availability bias**: rely on immediate information that comes to mind → ignore alternative opinions
    - **Illusory truth bias**: believe false information to be correct after repeated exposure, as it feels familiar

    Mitigate biases
    - DO NOT agree or disagree with any source's claim(s) at the first instance
    - DO consider alternative explanations / views
    - DO employ lateral reading to evaluate source's and alternative claim(s)
3. Guard our **buttons**

    Buttons are something that triggers strong emotions in you. Triggered buttons cause your emotions to override your objective critical thinking.

2.2 The Baloney Detection Toolkit

- BDTK 1: How **reliable** is the source of the claim?
    - Identify the source
    - Find out reliability of source (expertise of author)
    - Lateral reading (check what other reliable sources say)
- BDTK 2: What is the source's **perspective**?
    - Author's perspective/bias can be overtly inserted into communication → sway you to their way of thinking
    - Misrepresentation, falsification, fabrication
    - Source funding: where does the money come from? (conflict of interest)
- BDTK 3: Is the claimant providing **positive evidence**?
    - What is not scientific evidence: testimonials, eyewitness accounts, sworn statements, signed affidavits
    - Evidence must support the claim
    - Evidence must be reliable
    - Evidence must be relevant
    - Data as evidence should be reliable and not misrepresented - reverse image search

- BDTK 4: Where does **most of the evidence point**?
    - Well established scientific facts require a significant amount of scientific evidence
    - Need a majority of evidence showing that the claim or explanation isn't wrong
- BDTK 5: Have the claims been **verified** by somebody else?
    - Fact-checking sites
    - Reproducibility of scientific findings
- BDTK 6: Does the claimant use **flawed reasoning**?
    - Flaw in logic

3 Scientific Explanations and Models

3.1 Scientific Explanations - Theories and Hypotheses

- **Scientific explanation**: account of how or why something is the case, MUST be testable (subject to falsification)

  If the test fails, then the explanation needs to be revised or provide a new one

- **Hypothesis**: tentative or unproven, hasn't yet been subjected to any testing or falsification
  - a simple vague hunch
  - a finely detailed (but still speculative) account
- **Theory**: conceptual framework for providing explanations, general structures capable of explaining a much wider variety of phenomena than a hypothesis
  - well-tested, well confirmed rules and processes that reveal underlying explanations
  - breadth and depth of explanatory power

  Types of theories:
  - **Well-established**: repeatedly tested, provides depth and breath in explanatory power
  - **Obsolete/superseded**: previously thought to be correct, but came undone/replaced because of new evidence that proved it wrong
  - **Newly proposed**: explain phenomena that are already explained & try to explain anomalies (that current theories find hard supporting) – still under investigation and testing

3.2 Causation and Correlation

- **Causation**: cause always precedes effect
  - a combination of causes can lead to a single effect
  - can refer to groups rather than just individual facts or events
  - the same effect can result from separate and distinct causes
  - effects might not always result from a given cause in every case (causal link)
  - causation explanations can be negative
  - can involve a series of linked causes and effect: **proximate** (directly related, $A \Rightarrow B$) or **remote** causes ($A \Rightarrow B \Rightarrow C$)
- **Correlation**: the degree to which two properties/traits/characteristics move in coordination, in sync
  - **Perfect correlation**: direct 1 to 1 correspondence (rarely occurs)
  - **Positive correlation**: when one quantity goes up, the other goes up
  - **Negative correlation**: when one quantity goes up, the other goes down
  - **Strength** of correlation depends on how scattered the points are from best-fit line
- Causation $\neq$ Correlation

  Correlation is not enough to prove causation. Cause and effect relationships can be studied through
  - **Well-designed experiments**: change one independent variable while keeping all other variables constant
  - **Modelling**: modelled cause-effect relationship matches real world measurements

3.3 Types of Scientific Explanations

1. **Causal mechanism**: a linked chain of causes, remote cause ⇒ proximate causes ⇒ effect
2. **Underlying process**: describe observed phenomenon in terms of fundamental processes taking place at a more basic level
3. **Scientific laws**: generalised descriptions of regularities that have been found to occur in nature
4. **Function**: explain something based on the purpose it fulfils

3.4 Occam's Razor

- **Occam's Razor**: choose that explanation which is least complex and/or most plausible

  The greater the complexity, the greater the chance that something is wrong
- No guarantee that the simplest explanation is the correct explanation, but wise to first consider it, then move onto more complexed ones after we prove it wrong

3.5 Scientific Models

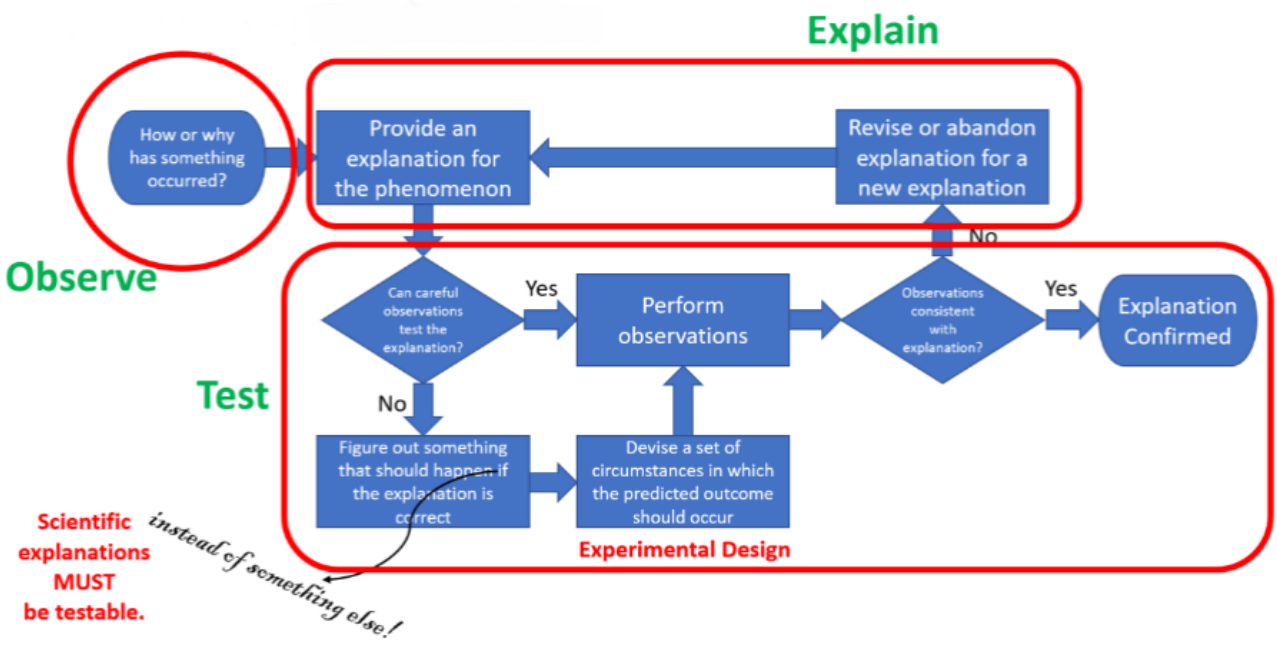
- **Scientific model**: cut-down, simplified representation of real-world objects/systems/events (idealisation of reality)
  1. **Physical model**: physical object represents some aspect of nature
     - Augmented with measurements to assist in optimisation and design of equipment or processes
     - Models can be larger than the actual thing they represent (e.g. chemical models, DNA)
  2. **Conceptual model**: cut-down version of reality with only the parts of interest included
     - Diagrams and figures: represent concept and ideas in science (extraneous details left out, but contains all important info to understand what is going on)
     - Can be abstract, do not look like the real-world object they represent (e.g. chemical structures)
  3. **Mathematical/Computer model**: use math to describe nature - the math involved is coded in computer to do tedious/complex calculations
     - When looking at correlation, we are mathematically modelling the r/s between two properties
     - Many laws in science are expressed using mathematical formula → used to derive even more expressions → when taken together, the equations represent how nature behaves
     - When modelling, scientist needs to consider all the necessary laws relevant to the phenomenon - a lot of data and equations
     - When taken tgt, they constitute a mathematical model
- **Prediction** VS **Projections**: projections differ from pure prediction in that they utilise "what if" scenarios
- **Theories** VS **Models**: models are created from concepts and principles provided in a theory/hypothesis → concrete applications of principles and concepts → used to test a hypothesis

  Models are subordinate to the higher-level theory which just expresses the concepts and principles

4 Experimentation and Uncertainty

4.1 Testing Scientific Observations

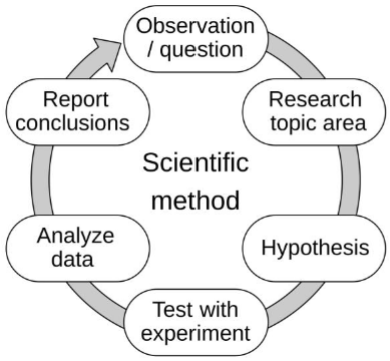
- Testing a scientific explanation:



- Due to poorly controlled scientific experiments:
  - **False confirmation**: believe experiment results support scientific explanation, when in fact it does not
  - **False rejection**: believe experiment results reject scientific explanation, when in fact it does not

4.2 Contemporary Scientific Research

- How contemporary scientific research is conducted



1. **Observation/Question**: observe something puzzling, find out how/why it occurs
2. **Research Topic Area**: do literature search - phenomenon you don't know about, or has also been observed by others - make sure you haven't missed anything
3. **Hypothesis**: may not necessarily need to be a hypothesis, after doing a literature search it could be an existing explanation, your own explanation (if is a new phenomenon), or a new explanation to challenge/improve pre-existing ones

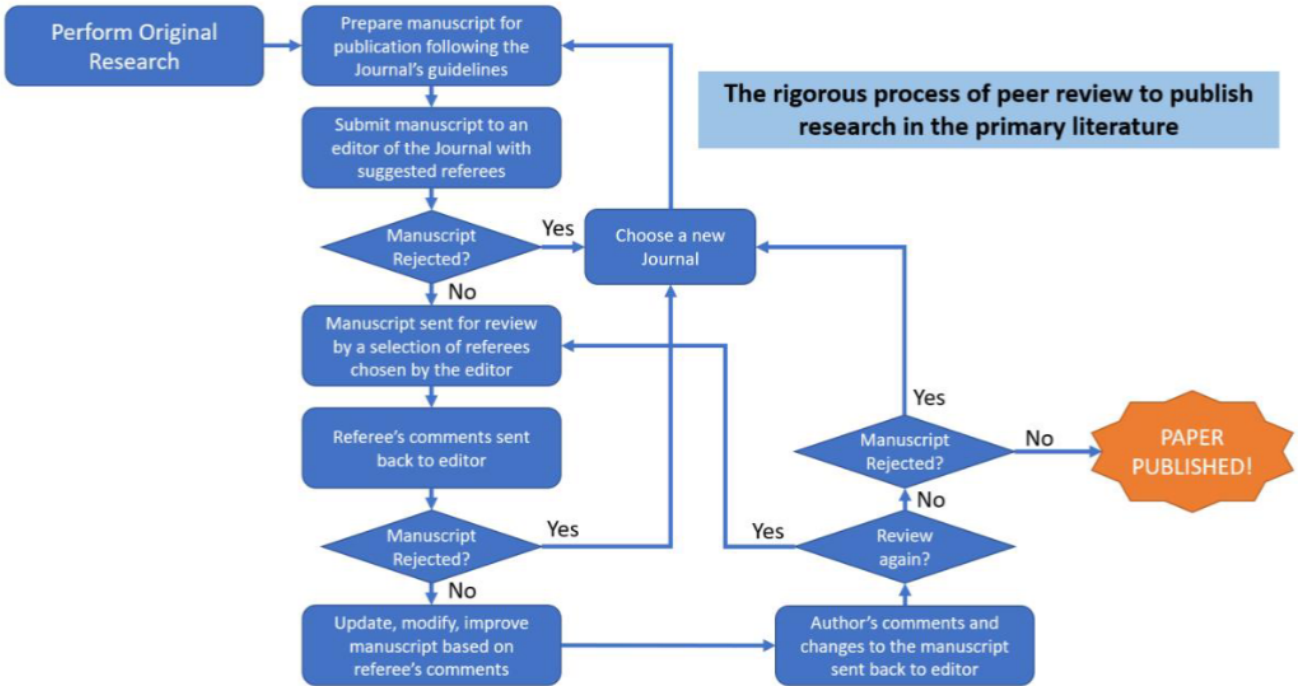
4. **Test with Experiment**: based on what we expect to happen if explanation were true, design experiment → avoid false confirmation/rejection

   Performing experiment is expensive → need funding → proposal needs to be prepared, submitted, reviewed and then funding will be awarded

   Even if funded, there needs to be results, or else no longer funded in the future → means that money can only be used for what it was awarded for, nothing else

5. **Analyse Data**: gather data, carefully analyse it
6. **Report Conclusion**: report findings of the work - always a requirement of funding bodies

- Publish scientific findings



Peer review makes the work reputable (BDTK 1)

4.3 Uncertainty and Precision

- **Uncertainty**: measurement can fall in a range of values
- **Margin of error**: range of possible values for the results of experiment, indicated by $\pm$ on the reading

  Requires a confidence level to determine the margin of error

  The larger the sample size, the lower the margin of error, thus affecting the confidence interval
- **Confidence interval** (CI): range of values covered by our $\pm$
- **Confidence level**: how confident we are that the true value lies in CI e.g. 95%
- **Precision**: higher precision means smaller uncertainty (more decimal places, more significant figures)

  Fewer **random errors**

4.4 Accuracy

- **Accuracy**: closeness of average of measurements to the true value
- **Systematic error**: difference between average measured value & true value
- Substantial systematic errors make results inaccurate - if they are so large as to exceed the uncertainty in the average → renders the uncertainty meaningless because it no longer can tell us anything about where the true value is

4.5 Tests Involving Comparison

- **Experimental group**: receive treatment

  Control group: do not receive treatment - serve as a baseline / comparison for the experimental group

  After the test, compare the two groups to assess if there is any difference in the outcome of interest

- **Randomised controlled double-blind experiments**:
  - **Random**: randomly assign participants to experimental / control group → eliminate selection bias & eliminate confounding (baseline characteristics are distributed equally)
  - **Sample size**: matters in whether we are able to detect a statistically significant difference between randomised groups

    Effect size: magnitude of difference in the outcome between the two groups

Sample size	Margin of error
25	$\pm 22\%$
50	$\pm 14\%$
100	$\pm 10\%$
250	$\pm 6\%$
500	$\pm 4\%$
1000	$\pm 3\%$
1500	$\pm 2.5\%$
2000	$\pm 2\%$

    Three rules of thumb: (to establish if we have a statistically significant difference)

    1. No overlap in the CIs $\Rightarrow$ statistically significant at 95% confidence level
    2. Overlap $<$ 1/3 of the range covered by the two CIs $\Rightarrow$ could be statistically significant
    3. Overlap $>$ 1/3 of the range covered by the two CIs $\Rightarrow$ probably not statistically significant
  - **Blinding**: withhold information about the assigned interventions from people involved in the test, who may potentially be influenced by this knowledge

    Double-blind: both participants and experimenters do not know who is in experimental or control group

    → eliminate additional bias from pre-conceived beliefs to creep into the outcome of the experiment

5 The Science of Climate Change

5.1 Nature of the Atmosphere

- Atmospheric composition
  - **Empedocles of Agrigentum**: All matter is made up of four universal elements: fire, air, water, earth. Elements could be mixed and produce complex substances. Combined by love (attractive force), separated by strife (repulsive force). Substances are temporary, elements are everlasting.
  - **Ancient Greeks**: Air was a single element. Aristotle water cycle: evaporation of water into the atmosphere $\leftrightarrow$ condensation as clouds and return to Earth as rain.
  - **Leonardo da Vinci**: Observed that air is not completely consumed during combustion and respiration. Atmosphere might be something other than a single substance.
  - **John Mayow**: Experiment: placed a lit candle in a closed container over water $\rightarrow$ water rose and replaced 1/14 of the air's volume before extinguishing candle. Showed that combustion and respiration require only a part of air ("spiritus nitroaereus").
  - **Jan Baptist van Helmont**: Experiment: burning charcoal gave off vapours. Many reactions produce substances ("gas sylvestre").
  - **Joseph Black**: Experiment: magnesium carbonate gave off a gas when heated, gas turned lime water milky, did not support life or combustion. Showed that the gas is naturally present in atmosphere, so air is not a single substance.
  - **Stephen Hales**: Published his work on plant transpiration. Atmosphere plays a role in the growth of plants.
- Problem of combustion
  - **Jean Rey**: Experiment: metals changed and gained weight when heated. Explanation: incorporation of air into metal.
  - **Johann Becher** & **Georg Stahl**: Phlogiston theory of combustion: phlogiston given off when substance burnt, remaining part is dephlogisticated part (substance's true form).

    Defects of the theory: 1. air has no role in phlogiston theory 2. phlogiston has negative mass.
  - **Michael Sendivogius**: Experiment: heating saltpetre releases "cibus vitae" (food of life).
  - **Cornelis Jacobszoon Drebbel**: "spiritous part of it that make it fit for respiration".
  - **Carl Wilhelm Scheele**: Experiment: heating mercury oxide and various nitrates produced "fire-air".
  - **Joseph Priestley**: Experiment: focusing sunlight on mercury oxide in a glass tube liberated "dephlogisticated air". Candles burned brighter in this gas, mice were more active and lived longer breathing this gas.
  - **Antoine-Laurent Lavoisier**: "vital air"
- Birth of Chemistry
  - **Henry Cavendish**: Water formed when "inflammable air" was burnt.
  - **Antoine-Laurent Lavoisier**: "water is not an element, but a compound made of inflammable air and vital air" $\rightarrow$ named inflammable air hydrogen, vital air oxygen.

    Oxygen combines with other substances during combustion. Respiration is a slow form of combustion. Law of conservation of mass.
- Who discovered oxygen?

- **Scheele**: first to isolate oxygen
- **Pristley**: first to publish
- **Lavoisier**: first to understand
- By Occam's razor, the principle of parsimony, **Sendivogus**: isolated oxygen and correctly associated it as part of atmosphere

5.2 Earth's Blanket

- **Jean-Baptiste Joseph Fourier**: Modelled Earth's temperature
  - Earth receives and radiates energy
  - Measured radiant heat & radiation from Sun $\rightarrow$ calculated Earth's temperature as $-18\,^{\circ}\mathrm{C}$
  - Atmosphere must act as insulator to prevent some radiant heat from escaping to space
  - First formulation of greenhouse effect
- **Greenhouse effect**: absorption of terrestrial infra-red radiation by gases in atmosphere (coined by Nils Ekholm)
- **John Tyndall**: Explained greenhouse effect -
  - Measured absorption of radiation by gases
  - Realised importance of water vapour in absorption of terrestrial radiation
  - Determined carbon dioxide is 90x more effective at absorbing infra-red radiation than air, methane is 403x more effective, water vapour is 16000x more effective
- **Eunice Foote**:
  - Compared how much water vapour, carbon dioxide, air were heated up in sun
  - Carbon dioxide has highest effect
  - Speculated that concentration of carbon dioxide could influence global temperatures
- **Arvid Högborm**:
  - Attempted to quantify sources of carbon dioxide emission
  - Industrial sources was comparable to natural sources
- **Svante Arrhenius**:
  - Considered effect of changing amount of carbon dioxide in atmosphere
  - Calculated that doubling atmosphere carbon dixoide would raise $5-6\,^{\circ}\mathrm{C}$
  - Concluded that emissions would lead to warming, but expected that global warning would take thousands of years
- **Guy Callendar**:
  - First to demonstrate Earth's surface temperature had increased over 50 years
  - Callendar effect: link between atmospheric carbon dioxide and global temperature
  - Thought warming would be beneficial
- **Charles Keeling**:

- Collected carbon dioxide samples at Mauna Loa Observatory in Hawaii
- Kelling curve: carbon dioxide levels were rising steadily

- **James Hansen**: Was 99% certain that the warming trend was not natural. Cause-and-effect relationship between increased carbon dioxide and warming trend.
- **Greenhouse effect**: process that cause surface to be warmer due to atmosphere

  Global warming: expected increase in magnitude of greenhouse effect

5.3 Model Building

Single-layer atmosphere model

- Earth **absorbs** solar energy from sun:

  Scale analysis: ignore energy emanating from Earth's core due to radioactive decay of fissile material

  $$\text{Energy absorbed} = S \times (1 - A) \times \pi R^2$$

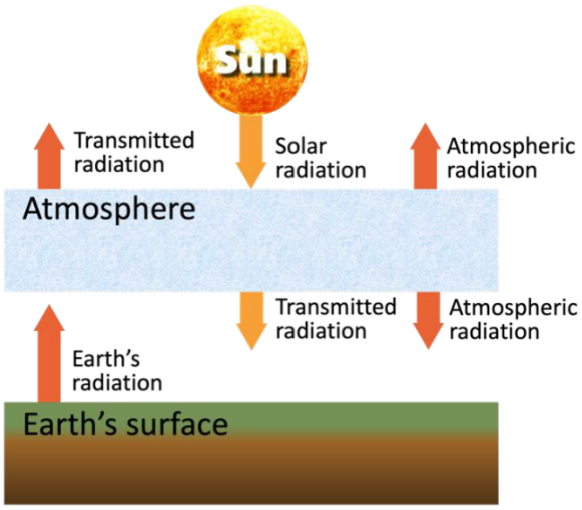
  where $S = 1370\,\mathrm{W\,m^{-2}}$ is the solar constant (energy per square meter per second), $A = 0.3$ is Earth's albedo (fraction of incoming solar radiation that is reflected by Earth's surface, clouds, atmosphere).
- Earth **emits** radiation back to space:

  By Stefan–Boltzman law,

  $$\text{Energy emitted} = \sigma T_E^4 \times 4\pi R^2$$

  where $\sigma = 5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$ is Stefan–Boltzmann constant.
- Equate amount of energy absorbed & energy emitted: $T_E = 255\,\mathrm{K} = -18\,^\circ\mathrm{C}$ (Earth's **effective temperature**)
- Howver, did not account for effect of atmosphere $\rightarrow$ need to allow atmosphere to absorb and emit radiation

  Include two parameters to account for absorption of solar radiation & absorption of terrestrial radiation



By iterative process, temperature is $288\,\mathrm{K} = 15\,^\circ\mathrm{C}$. With atmosphere, Earth's surface is $33\,^\circ\mathrm{C}$ warmer (**magnitude of greenhouse effect**). Instead of iterative process, simple mathematical model:

$$F_g = F_s \cdot \frac{1 + \tau_s}{1 + \tau_g}$$

where F_s is solar radiation, F_g is terrestrial radiation, τ_s is solar transmittance, τ_g is terrestrial transmittance.

6 Establishing Scientific Consensus on Climate Change

6.1 Scientific Consensus

- **Weather**: conditions in one location at one time (short term)

  Climate: conditions in one region over a long time (long term)

  Climate change: shift in long-term weather conditions

- Current scientific consensus:
  - Temperatures have risen by more than 1 °C since the 1850-1900 global average, and that it is "unequivocal that human influence has warmed the atmosphere, ocean and land"
  - Earth's climate has changed due to human activity as "unprecedented" in the previous hundreds of thousands of years, with some of the changes as now being inevitable and "irreversible".
- **Scientific consensus** is achieved when
  - great majority of scientists of a given field agree upon a position
  - based on a large amount of evidence.
- Scientific consensus is not an appeal to authority
  - **Fallacy of appeal to authority**: when said authority is not a subject matter expert
  - Scientific consensus is formed by community of experts
- **Guy Callendar**:
  - Convinced that nearly all CO2 produced by fossil fuel combustion had remained in atmosphere
  - Suggested that increase in CO2 may account for rise of average temperature in northern latitudes
- Scientists at the time
  - Agreed that CO2 is a greenhouse gas, increase in concentrations might affect climate
  - Argued that water vapour is greenhouse gas and much more than CO2 $\rightarrow$ sceptical that small increase in CO2 could have big effect
  - However: water vapour and carbon dioxide absorb at diff wavelengths $\rightarrow$ increase in carbon dioxide significantly increases absorption of infra-red radiation at certain wavelengths
- **Roger Revelle** & **Hans Suess**: advocated for accurate measurements of CO2
- **Charles Keeling**: measured CO2 at Mauna Loa
- Scientific consensus informs public policy
- Scientific consensus established on theory and impact

6.2 A Question of When

- Scientific consensus established on what will happen, but not when
- **James Hansen**: provided first estimate of natural climate variability
  - Calculate variability in global average temperature was 0.13 °C, such that rise of 0.4 °C would give 99% confidence that global warming had been observed.
  - Argued this would "constitute convincing evidence of a cause and effect relationship"
- Statistics rule of thumb: **68-95-99.7 rule**
  - 68% events occur within 1 standard deviation from mean
  - **95%** events occur within 2 standard deviations from mean (used to identify **statistical significance**)
  - 99.7% events occur within 3 standard deviations from mean
- **Intergovernmental Panel on Climate Change** (IPCC): provides objective scientific information relevant to understanding human-induced climate change
  - 1st Assessment Report in 1990, 2nd Assessment Report in 1995, 3rd Assessment Report in 2001
- Perception of scientific consensus on climate change
  - Public: many do not think that "most scientists believe that global warming is occurring"
  - Scientists: most/all agree with the scientific consensus that human-induced climate change is real and happening

6.3 Convincing the Scientific Community

- 4 major keepers of records on global temperatures
- Very good correlation ($> 99\%$) but not perfect
  - Imperfect coverage - deal with gaps in slightly different ways
  - Homogenisation: correct for issues e.g. missing data, changes in instrumentation
- **Proxy method**: measure a variable which correlates with the variable of interest, then use it to infer the value of the variable of interest $\rightarrow$ reconstruct past temperatures
  - **Dendroclimatology**: tree rings are wider when conditions favour growth, narrower when otherwise
  - **Coral reefs**: composition of oxygen isotopes present in coral's carbonate chemistry
  - **Ice cores**: composition of oxygen found in water
- **Global carbon cycle**: atmosphere, crust, dissolved in water
- **Suess effect**: fossil fuels are devoid of carbon-14 $\rightarrow$ burning fossil fuels increases carbon-12, leaves carbon-14 unchanged $\rightarrow$ decrease in ratio of carbon-14 to carbon-12 in atmosphere
- Scientists achieve understanding of a phenomenon P if they construct an appropriate model of P on the basis of a theory T.

7 On the Mongering of Doubt

7.1 The Art of Doubt

- **John Sununu**
  - no training in climate science, but criticised Hansen's work - believed that the science underlying the link between global warming and the combustion of fossil fuels was insufficient to warrant government action or societal expense
  - heavily edited Hansen's testimony, leaving it meaningless
  - opposed climate change policy and any regulations limiting carbon dixoide - thought would stifle economic growth
  - appointed climate change sceptic to US negotiating team - given orders to prevent any US commitment to limits → no global treaty forged
- **Fallacy of appeal to authority**: when said authority is not a subject matter expert
- Climate change deniers use authority to promote their own agenda
- **George C. Marshall Institute**: Jastrow, Seitz, Nierenberg (contrarian scientists)
  - New enemy: **environmental extremism** → viewed environmentalism to be socialism, since envt issues required govt intervention → popular **neo-liberalism** denounces such intervention
  - Driven by political agenda to thwart government regulation → cast doubt on the science behind many of these environmental issues
  - Argued that global warming was caused by natural variations in solar radiation - any warming caused by greenhouse emissions is swamped by natural climate variations
- Significant fraction of the public accepts the deniers' allegations as true, or at least are confused by them → do not know what to think, whom to trust → erode public support for decisive action

7.2 Narratives of the Sceptic

- Apply BDTK to articles written about climate change
- **Indicators** of global warming
  1. Land surface air temperature increasing
  2. Sea surface temperature increasing
  3. Air temperature over oceans increasing
  4. Lower troposphere temperature increasing
  5. Ocean heat content increasing
  6. Sea level rising
  7. Specific humidity rising
  8. Glaciers retreating
  9. Snow cover decreasing
  10. Sea ice shrunk
- **Human fingerprints** on climate change

1. 30 billion tonnes of CO2 per year
2. Less oxygen in the air
3. More fossil fuel carbon in the air
4. More fossil fuel carbon in coral
5. Less infra-red radiation escaping to space
6. More infra-red radiation returning to Earth
7. Nights warm faster than days
8. Cooling stratosphere
9. Rising tropopause
10. Shrinking thermosphere

7.3 Bias and Denial

- Forms of denial used to convince the public to delay action on climate change

  1. **Science denial**: That the science of climate change is not settled. That there is no consensus. That climate change is just part of the natural cycle.
  2. **Economic denial**: That climate change is too expensive to fix. This is a form of self-fulfilling prophecy.
  3. **Humanitarian denial**: That climate change is good for us. That longer, warmer summers make farming more productive. That plants need carbon dioxide and so more of it acts as a fertiliser. That warmer winters will lead to fewer deaths.
  4. **Political denial**: That we cannot take action because other countries are not taking action.
  5. **Crisis denial**: That we shouldn't rush into committing to binding international agreements, given the uncertainty raised by the previous areas of denial.

- Cognitive biases:

  1. **Time-discounting bias**: discount the future to a greater degree than can be rationally defended
  2. **Illusory truth bias**: tend to see things in a more positive light than is objectively the case
  3. **Self-serving bias**: tend to determine preference for outcome based on self-interest

8 On the Reliability of Projected Climate Change

8.1 Reliability of Climate Models

Climate models prove their reliability through hindcasting and successful forecasting

- **Climate model**: computer programs that calculate climate and change in climate
- **Projection**: model-derived estimate of future climate
- **Prediction**: projection that is branded most likely
- **Scenario**: coherent, internally consistent, and plausible description of a possible future state of the world - have a demographic, socio-political, economic, and technological storyline
- **Hindcasting**: test models by reproducing past obserbations
- Climate models divide the planet up into **grid cells** $\rightarrow$ calculate average climate of each grid cell
- **Parameterisation**: values of variables are defined in the computer code rather than being calculated by the model itself - main source of uncertainty in climate models
- **Paleoclimate model**: reproduce proxy temperature records for much earlier climates

Impact of feedback on model projection uncertainty

- **Positive feedback**: output of system is fed back in a manner that increases fluctuation in output $\rightarrow$ destabilise the system via exponential growth
- **Negative feedback**: output of system is fed back in a manner that reduces fluctuation in output $\rightarrow$ stabilise the system
- **Positive coupling**: increase in one element leads to increase in connected element (same direction)
- **Negative coupling**: increase in one element leads to decrease in connected element (opposite directions)
- Photosynthetic rate of plants & concentration of atmospheric carbon dioxide (negative feedback)
- Mass of ice sheet & elevation of ice sheet (positive feedback)
- Surface temperature & water (positive feedback, negative feedback)
- In general, negative feedback loop has odd number of negative couplings; positive feedback has even number of negative couplings
- Carbon dioxide concentration & temperature (positive feedback) $\rightarrow$ further increase temperature
- **Climate sensitivity**: net effect of initial warming due to doubling CO2 and the feedbacks in Earth system

8.2 Performance of Climate Models

- **Special Report on Emissions Scenarios**: scenarios constructed to explore future developments in global environment

  The four storylines combine two sets of divergent tendencies: strong economic values vs strong environmental values, increasing globalisation vs increasing regionalisation

- **Scenario Matrix Architecture**: scenario framework used in 6th IPCC Assessment Report

- **Representative Concentration Pathways** (RCPs): describe different levels of greenhouse gases and other radiative forcings that might occur in the future
- **Shared Socioeconomic Pathways** (SSPs): describe how socioeconomic factors may change over the century - population, economic growth, education, urbanisation, rate of technological development
- Possible future climate scenarios:

SSP1 Sustainability—Taking the Green Road: sustainability-focused growth and equality

SSP2 Middle of the Road: trends broadly follow their historical patterns

SSP3 Regional Rivalry—A Rocky Road: fragmented world of resurgent nationalism

SSP4 A Road Divided: highly unequal investments in human capital, increasing disparities in economic opportunity and political power

SSP5 Fossil-fueled Development—Taking the Highway: rapid and unconstrained growth in economic output and energy use

- Greenhouse gas emissions: SSP3 SSP5 high and very high, SSP2 intermediate, SSP1 low and very low
- Temperature: SSP1 $1.0 \sim 1.8\,^{\circ}$C, SSP2 $2.1 \sim 3.5\,^{\circ}$C, SSP5 $3.3 \sim 5.7\,^{\circ}$C
  Amount of warming is not equal: middle of continents $>$ coastal areas, high latitudes $>$ low latitudes
- Precipitation: increase at high latitudes, decrease near the equator and at mid-latitudes
- Sea level: continue to rise due to continuing deep ocean warming, ice sheet melt

8.3 Safeguarding the Global Commons

- Principles governing international actions

  1. Precautionary Principle: lack of scientific certainty should not prevent appropriate action being taken
  2. Polluters Should Pay: carbon dioxide and many other greenhouse gases are global pollutants, they affect the global commons
  3. Equity:
     Intergenerational equity: we hold the natural environment of our planet in common with all members of our species: past generations, present generation, future generations
     International equity: developed countries should take the lead in combatting climate change, because they have a legacy of historical emissions that they used to industrialise

- **Contraction and Convergence proposal**

  1. **Contraction**: the world as a whole agrees to follow the envelope curve
  2. **Convergence**: CO2 emissions allocated to countries so as to share the emissions equally between all humans $\rightarrow$ emissions converge to their 2030 allocations
  3. **Trading of emissions**: those that have more than they need can sell to those that want to emit more $\rightarrow$ move money from developed nations to developing nations $\rightarrow$ develop non-fossil fuel energy systems

9 Restoration of Nature

9.1 Loss of Biodiversity

- 1819: Rapid deforestation with British colonisation
- 1900: 90% of primeval forest cleared for agriculture
- 1959: Rapid urbanisation & large-scale land reclamation with independence
- 1973: $<$ 30% land area natural vegetation
- 1990: $>$ 99% of original forest loss, $>$ 50% Singapore is urbanised

9.2 Green Singapore

- Evolving visions of a green Singapore
  - Vision I: Garden City $\rightarrow$ economic development, "first world" image
  - Vision II: City in a Garden $\rightarrow$ recreational spaces, enhancing urban areas
  - Vision III: Biophilic City in a Garden $\rightarrow$ connectivity, natural heritage protection, community involvement
  - Vision IV: City in Nature $\rightarrow$ conserving and restoring natural ecosystems, world class parks and gardens, ecological connectivity
- **Buffer parks**: protect nature reserves

9.3 Waterways

- Rivers have always been used by human communities as a sewage line e.g. throw rubbish, send sewage in
- **Anoxic waters**: areas of sea water, fresh water, or groundwater that are depleted (no living creatures in it) - polluted
- 17 reservoirs in Singapore to collect and store rainwater and used water
- Immigration of **smooth-coated otters** from southern Johor (**source**) to Singapore (**sink**)
- Mandai mangroves and mudflat declared as a nature reserve, 2018

9.4 Policies

- SGP2030
- Green spaces
- Ecological Profiling Exercise (EPE): development sites (e.g. state land forest fragments) are evaluated holistically by NParks using these questions: How is it linked to a source habitat? Does it contribute to a nature corridor?
- One Million Trees
- Forest restoration

10 Connectivity of Nature

10.1 Park Connectors

- A system of parks, connectors and nature reserves in Singapore
- Case in point: the return of the southern pied hornbill to mainland Singapore
- Common palm civet: disperse tree seeds across SG
- Greater mouse deer: rediscovered on Pulau Ubin, seed disperser and prey species
- Malayan pangolin (Manis javanica): regulates the ant and termite populations & their digging action (in search of prey and while feeding) helps to aerate the soil
- Leopard cat: buffer parks help increase viable area for the animal, adaptable species

10.2 Fragmentation

- Fragmented habitats isolate animal and plant populations → roads are deadly as animals attempt to travel between fragments → roadkills
- Categorise wild animals based on their response to urban environments:
  1. Urban avoider (shy): confined to natural habitats e.g. leopard cat
  2. Urban adapter (adaptable): occur at margins, or partly naturalised urban areas, occasionally straying into urban areas e.g. long-tailed macaque, smooth-coated otter, common palm civet
  3. Urban exploiter (bold): e.g. commensals
- Culvert: tunnel goes below road surface
- Rope bridge: meant for arboreal animals (animals that climb on trees)
- Eco-link: links the two forests

10.3 Establishing Connectivity

- Landscape changes around Berlayer Creek

  Reclamation: dramatic changes to SG's coastline → loss of coastal habitats and their wild communities
- 1930: Freshwater swamp has been drained, Berlayer River has been canalised, southern mangroves are intact
- Today: Marginal habitats have survived and are protected

10.4 Fragmentation of Bukit Timah Nature Reserve

- Impact of fragmentation and high visitorship at Bukit Timah hill
- BTNR = a cluster of forest micro-fragments plus a series of existing impacts
- Sources of disturbance: roads, oaths, human traffic (trail compaction, illegal night walks), quarries, condominiums (mosquito fogging)
- Scientists and naturalists raised concern about BTNR's health over the decades
- 2014: NParks announces the closure of BTNR

10.5 Connectivity and Singapore Master Plan

- Singapore Master Plan 2019 (review every five years)
- The brown patches will make way for growth
- Evaluation of protection now involves community engagement
- Relevance of ecological connectivity is highlighted

10.6 Connectivity and Human-wildlife Coexistence

- Shy wildlife e.g. Raffles Banded Langur
- Some wildlife adapt to forest edge/urban environment e.g. long-tailed macaque, common palm civet, wild pigs, smooth-coated otter
- Ensuring human-wildlife coexistence: tapping the expertise of a dedicated landscape (ground up working groups) - NGOs, researchers, interest groups/individuals

11 Hinterland of Resources

11.1 Carbon Emissions

- How coal was formed:
  1. Before the dinosaurs, many giant plants died in swamps
  2. Over millions of years, the plants were buried under water and dirt - carbon locked in, deposited very deep in the layers of Earth
  3. Heat and pressure turned the dead plants into coal
  4. Now: humans extract and use it (oil, gas, coal)
- What generates greenhouse gas emissions?
  - 3/4 come from energy use
  - 1/5 come from agriculture and land use
  - 1/4 come from food system as a whole [+ processing, packaging, transport and retail]
  - 8% from industry and waste

11.2 Ecological Deficit

- **Ecological deficit**: footprint of a population exceeds the biocapacity of the area available to that population (ability to sustain human population)
- Singapore: little natural resources, highly urbanised → biocapacity depleted
- Earth Overshoot Day marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year

  A country's overshoot day = the date on which Earth Overshoot Day would fall, if all of humanity consumed like the people in that country (earlier date is worse)
- Positive correlation b/w ecological footprint & human development index
- **Principle of equity**
  - Higher risks for coastal cities - more vulnerable to impacts of climate change → disproportionally affected (inequity)
  - Paris Agreement associates the principle of equity with the broader goals of poverty eradication and sustainable development
  - Recognising that effective responses to climate change require a global collective effort that may be guided by the 2015 UN SDGs

11.3 Concept of Hinterland

- **The hinterland**:
  - The remote areas of a country away from the coast or the banks of major rivers
  - The rural area economically tied to an urban catchment area
  - "a large, powerful urban community (metropolis) and the surrounding territory (hinterland) which the metropolis dominates through mainly economic means"
- City → urban fringe → rural/hinterland

11.4 Singapore's Hinterland – Food

- Import over 90% of food supply, vulnerable to disruptions in transport routes, export bans, climate change
- SFA: Three Food Baskets
    1. Diversify import sources
    2. Grow local (30 by 30)
    3. Grow overseas
- Food targets in Singapore Green Plan (SGP2030):
    - Build the capability and capacity of our agri-food industry to produce 30% of Singapore's nutritional needs locally and sustainably

11.5 Singapore's Hinterland – Water

- Four National Taps: diversified supply of water
    1. Water from local catchment
    2. Imported water
    3. Highly-purified reclaimed water (NEWater)
    4. Desalinated water
- Demand will only increase with time $\rightarrow$ proportion of water supply by NEWater increases
- Through a network of rivers, canals and drains, rain is channelled to 17 reservoirs
- Water targets in Singapore Green Plan (SGP2030):
    - Reduce household water consumption to 130 litres per capita per day
    - Singapore's first integrated waste and used water treatment facility to be 100% energy self-sufficient (Tuas Nexus)

11.6 Sustainable Development Goals

- SDGs are a set of goals under the **2030 Agenda for Sustainable Development** (2030 Agenda) - a global development framework
- 17 SDGs with 169 targets, 247 indicators used to measure progress towards reaching the targets

12 Fallacies in the Name of Science

12.1 Fallacies in the Name of Science

Fallacy: flawed reasoning or logic, incorrect or improper use of the scientific method, or a deliberate act to misrepresent something.

1. **False anomalies**: fraudulently present some phenomenon as being mysterious, not explicable by science & provide their own explanation (extraordinary claim)
    - Purposefully leave out evidence in support of a regular scientific explanation, or misrepresent/falsify evidence in support of their claim
    - E.g. Crop circles: tram lines ignored when this false anomaly is presented
2. **Questionable arguments by elimination**: consider evidence that an alternative explanation is wrong to be actual evidence in support of their explanation for some phenomenon
    - E.g. Extrasensory preception (ESP): rules out the possibility of luck at guessing the card, but it does NOT prove that the person has ESP
    - Eliminating rival explanations does not provide evidence for your favourite explanation $\rightarrow$ need to find positive evidence directly in support
3. **Illicit causal inferences**: some out of the ordinary occurrence precedes some other out of the ordinary occurrence $\rightarrow$ conclude that some causal link between them
    - E.g. thinking of a friend, then the person calls you $\rightarrow$ you have ESP
4. **Unsupported anologies and similarities**: the fact that an explanation works in one case is given as evidence for the correctness of a similar explanation in another case
    - A well-chosen similarity guides us to a possible explanation; it should not be thought of as providing evidence
    - E.g. Astrology: claims that because the moon influences the tides on Earth, the positions of the planets influence formation of human personality
5. **Untestable explanations and predictions**: explanation cannot be falsified (NOT a scientific explanation)
    - E.g. Conspiracy theories: immune to falsification
    - Claim that any real evidence that their theory is wrong is fabricated, lack of evidence IS actual evidence of their conspiracy
6. **Empty jargon**: string together scientific terms
    - E.g. telekinesis
7. **Ad hoc rescues**: when a scientific test of an explanation or claim continues to fail those tests, refuse to admit they are wrong
8. **Exploiting uncertainty**: recast tiny levels of uncertainty into large ones
    - E.g. Double mongering: attack climate change

12.2 Science and Pseudoscience

Ways that we cannot use to distinguish science from pseudoscience

1. The distinction between science and pseudoscience has nothing to do with the distinction between "hard" and "soft" sciences
2. The distinction between science and pseudoscience cannot be drawn along lines of scientific discipline
3. Science cannot be distinguished from pseudoscience simply on the basis of the results each produces

Features that distinguish science from pseudoscience

Science	**Pseudoscience**
Is self-correcting	Not self-correcting
As a scientific discipline develops, it gradually produces a maturing body of explanatory/theoretical findings	Produces very little theory
Findings are always open to revision	Claims rarely change much over time
Embraces scepticism	Views scepticism as a sign of narrow-mindedness