SCIENCE AND SCIENTIFIC STUDIES

Epistemology- Branch of philosophy concerned with the nature and scope (limitations) of knowledge

Theoretical Knowledge

- Knowledge based on rational thinking & intellectual reasoning
- Expressed as hypotheses, principles, laws & theories
- Explain a problem or phenomenon

Practical knowledge

- Knowledge gained through experience
- It is applied in performing some tasks
- It is job dependent
- Eg. Professionals, athletes, artists, performers etc

Scientific knowledge/ Empirical knowledge

- Organized theoretical & practical knowledge
- Involves systematic observation, experimentation, testing, evaluation or any other method of inquiry & investigation
- Always subjected to revision, modification, or discarded later
- Systematic knowledge gained through scientific investigation
- Self-correcting & testability are the key features

Differentiate Science and Not Science

Science	Not Science
• Always follows certain rules	• Does not obey proved & accepted principles
• Always based on observed facts	• Not based on observed facts
• Always testable or verifiable	• Not testable or verifiable
• Based on observation, experimentation and analysis	• Based simply on faith and belief
• Always substantiated by evidences	• Just casual comments, ideas, beliefs, notions and opinions- no evidence

Pseudoscience

- Also called fringe science/ alternative science
- Methodology, speculation, belief or practice which is claimed to be legitimately scientific but does not meet standards required for science
- Does not follow scientific methodology
- No supporting evidences
- Examples are telepathy, pre-cognition, faith healing, necromancy, witchcraft etc.

Hypotheses

A hypothesis is a tentative generalization, the validity of which has got to be tested. A hypothesis is an educated guess, based on observations and accumulated previous knowledge. Usually, a hypothesis

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can be supported or refuted through experimentation or more observation. On the basis of the hypothesis facts are observed and collected. When, by verification, the hypothesis is found to be true, a theory is obtained.

A good scientific hypothesis must be falsifiable. According to Karl popper a scientific hypothesis must be tested empirically against nature and accepted only if such testing cannot falsify it.

Characteristics of hypothesis:

A hypothesis must possess the following characteristics

i. Hypothesis should be clear and precise.
ii. Hypothesis should be capable of being tested.
iii. It should state relationship between variables.
iv. It should be limited in scope and must be specific.
v. Hypothesis should be stated as far as possible in the most simple terms so that the same is easily understandable by all concerned.
vi. It should be consistent with most known facts, i.e. it must be consistent with a substantial body of established facts.
vii. Hypothesis should be amenable to testing within a reasonable time.
viii. It must explain the facts that gave rise to the need foe explanation.

Uses of Hypothesis:

i. Hypothesis forms the starting point of investigation
ii. It makes observation and experiment possible
iii. It is an aid to explanation
iv. Hypothesis makes deductions possible

A hypothesis is indispensable for any scientific investigation. The hypothesis always guides and gives direction to the scientific investigation. Without a hypothesis, a scientist cannot know as to what to observe and how to observe. Without a hypothesis, an investigation becomes unfocussed.

Theory

A scientific theory represents a hypothesis, or a group of related hypotheses, which has been confirmed through repeated experimental tests. Theories are not easily discarded. It is only when, after repeated experimental tests, the new phenomenon cannot be accommodated that scientists seriously question the theory and attempt to modify it. A theory is valid as long as there is no evidence to dispute it.

A theory is:

- Internally consistent and compatible with the evidence
- Firmly grounded in and based upon evidence
- Tested against a wide range of phenomena
- Demonstrably effective in problem-solving

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All scientific disciplines have well-established, fundamental theories. For example, the theory of evolution by natural selection.

Laws of science

Scientific laws are generalizations about the behaviour or operation of nature. They are based on repeated observations and they usually do not contain an explanation for why these patterns occur. Laws *describe* phenomena, often mathematically. Theories, however, *explain* phenomena. For example the law of evolution is that members of populations change genetically (and as a result morphologically) over time. The law is explained by hypotheses or theories. Natural selection and genetic drift are both theories that seek to provide mechanisms to explain evolution. A theory may contain a set of laws, or a theory may be implied from an empirically determined law.

Theory	**Law**
Explains why	Describes how
Agrees with observations	Summarizes observations
Usually an equation	Predicts new discoveries

Scientific Fact

An undisputed piece of information derived from observation is called scientific fact. It is any observation that has been repeatedly confirmed and accepted as true or any scientific observation that has not been refuted.

Scientific Temper

- Is the rational and ideological outlook of mankind on issues and problems
- It is free from bias, prejudices and preconceived notions
- It involves rational thinking, intellectual reasoning, weighing evidences and sifting truth in all matters that are amenable to inquiry or investigation
- Creativity, openness and tolerance are its characteristics
- It involves observation, analysis, verification and argument

Scientific Attitude

- Is the attributes characteristic of scientific temper
- It includes mental activism, curiosity, precision and perfection, humility, intellectual honesty, open-mindedeness, rationality without superstition or bias, self-lessness, objectivity, systematic approach etc.

Empiricism

Empiricism is a theory of knowledge which states that all knowledge is derived from experience. Sense experience is the only source of knowledge. Inferential beliefs, beliefs that are not directly

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observable, must be justified by basic empirical beliefs. Empiricists do not believe things that cannot be confirmed or falsified by empirical evidence.

Empiricism is a fundamental part of scientific method, where all hypotheses and theories must be tested against observations of natural world. Science is **methodologically empirical** in nature and all evidence in science must be empirical. In science **empirical** literally means **experimental**

Vocabulary of Science

- Vocabulary is a set of defined or explained terms, words, symbols or signs, which is used for expression or communication
- Science vocabulary is a complete set of terms, symbols and signs used to specify or designate various processes, phenomena and entities for the purpose of effective expression and communication
- International Science Vocabulary (ISV) has scientific terms and specialised words whose origin may or may not be clear
- Many science terms have root words from Latin or Greek
- Examples: Chromophore- *Chroma* = colour; *pherein*= to bear; Cleistogamy- *Kleistos* = closed; *gamos* = marriage; Herbivore – *Herba* = green crop; *vorare* = to devour
- Science vocabulary uses many prefixes and suffices
- **Prefix** is added in front of the root word to elaborate, qualify or change the meaning of the term
- Examples: Anaerobe - *an*= without; air = air; *bios* = life; *Epi*petalous- *Epi*= upon; *petalon*= leaf
- **Suffix** is added at the end of the root word which completes the root word, changes its meaning, indicate a value, quality, form etc
- Example: Limnology- *limne*= lake; *logos*= study

Science Disciplines

- Science includes various disciplines which is broadly divided into pure sciences and applied sciences.
- **Pure science** is the basic science which includes biological science, physical science and earth science. Biological science includes the fields of life sciences such as botany, zoology, ecology, chemistry etc. Physical science includes the fields like physics and chemistry while earth science includes geology, astronomy etc.
- **Applied science** uses the knowledge from the pure science to solve practical problems often using technology. Biotechnology, microbiology, chemical engineering, computer technology, nanotechnology, electronics, etc. are examples

Scientific Methodology

The Scientific Method involves a series of steps that are used to investigate a natural occurrence.

1. Problem/Question: Develop a question or problem that can be solved through experimentation.

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2. Observation/Research: Make observations and research your topic of interest.

3. Formulate a Hypothesis: Predict a possible answer to the problem or question.

4. Experiment: Develop and follow a procedure.

5. Collect and Analyze Results: Modify the procedure if needed. Confirm the results by retesting.

6. Conclusion: Include a statement that accepts or rejects the hypothesis. Make recommendations for further study and possible improvements to the procedure.

7. Communicate the Results: Be prepared to present the project to an audience.

1. Problem/Question:

John watches his grandmother bake bread. He ask his grandmother what makes the bread rise. She explains that yeast releases a gas as it feeds on sugar. John wonders if the amount of sugar used in the recipe will affect the size of the bread loaf?

2. Observation/Research: John researches the areas of baking and fermentation and tries to come up with a way to test his question.

3. Formulate a Hypothesis: After talking with his teacher and conducting further research, he comes up with a hypothesis. "If more sugar is added, then the bread will rise higher."

4. Experiment: His teacher helps him come up with a procedure and list of needed materials. She discusses with John how to determine the control group. Because his grandmother always used 50g of sugar in her recipe, John is going to use that amount in his control group. John's teacher reminds him to keep all other factors the same so that any observed changes in the bread can be attributed to the variation in the amount of sugar. Trials refer to replicate groups that are exposed to the same conditions in an experiment. John is going to test each sugar variable 3 times.

5. Collect and Analyze Results: John gets all his materials together and carries out his experiment. John comes up with a table he can use to record his data. He analyses his data statistically.

6. Conclusion: John finds that 70g of sugar produces the largest loaf.

7. Communicate the Results: John tells his grandmother about his findings and prepares to present his project in Science class.

Formulation of Hypothesis

- **Analogy** -similar situations may lead to similar results. Eg.-chimpanzees raise their young in certain ways -hypothesize that gorillas do the same
- **Induction** -from observations of specific phenomena which are then hypothesized to reflect a general pattern. An ecologist find that an insect species killed several trees - hypothesize that that species is the cause of increased tree death throughout the forest.
- **Deduction** applies general principles to predict specific results. Eg. an analysis of well understood physical principles applied to the conditions of the atmosphere -increasing the amount of CO_2 will lead to an increase in global temperature.

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- **Intuition** -the scientist has little, if any, concrete information to guide him/ her; the hypothesis is simply a statement as to what "seems right".
- **Chance** -scientist makes a sudden connection between the problem and a common event.
- **Serendipity** -an unexpected observation is made, this along with the wisdom of the observer, leads to a novel insight or important discovery.

Deduction

- Applies general principles to predict specific results
- Conclusions drawn by reasoning from a general principle to a particular case
- Theory → data collection → analysis
- Also called **theory-data collection- analysis method**
- E.g.
  - *'All Keralites like rice'*
  - *'Mr. X is a Keralite'*
  - *'Therefore Mr. X likes rice'*

Hypothetico-deductive Model

- Scientific inquiry proceeds by formulating a hypothesis about the behavior of the phenomenon- an experiment conducted systematically- results of the experiment are analyzed (statistically)- original theory is re-examined and a revised hypothesis is created- test the revised hypothesis with new, more precise, controlled experiments
- Values *reliability* and *validity*- the results can be generalized beyond the specific experimental setting in the laboratory

Steps in hypothetico-deductive method:

1. Gather data (observations about something that is unknown, unexplained, or new)
2. Hypothesize an explanation for those observations.
3. Deduce a consequence of that explanation (a prediction). Formulate an experiment to see if the predicted consequence is observed.
4. Wait for corroboration. If there is corroboration, go to step 3. If not, the hypothesis is falsified. Go to step 2.

Induction

- Uses specific observations to construct general scientific principles
- Final conclusions and generalisations from specific observations and analysis of known factors
- Specific observations → analysis → formulation of hypothesis → conclusions and theory
- Also called data collection- analysis method
- E.g. *if, in a number of cases, it is observed that educated girls have got expensive habits, one may conclude that all educated girls have got expensive habits.*

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Inductive Model

Begins with natural phenomena- observes in the real world (not in lab) without any preconceived idea- attempts to describe a framework or model that explains the phenomenon- return to the real world to make further specific observations that validate or contradict the original framework- results are then incorporated into a modified framework.

Auxiliary Hypothesis

- Supplementary hypothesis constructed for testing of a scientific proposition
- Hypothesis other than the test hypothesis which is assumed to be true and is needed to derive the test implication
- Required to support the test result
- Test result is considered true if the test hypothesis and auxiliary hypothesis are true

Adhoc Hypothesis

- An auxiliary hypothesis introduced for the sole purpose of saving a test hypothesis from being falsified
- Added to the results of an experiment to try to explain away contrary evidence
- Eg. Wegener -theory of continental drift - could not explain how continents move- suggested that gravity was the force behind the movement of continents- no scientific evidence - scientists did show that gravity was too weak a force to account for the movement of continents
- Are not necessarily incorrect
- Often characteristic of pseudoscientific subjects

Revision of Scientific Theories and Laws

- A scientific theory must be tentative- always subject to revision or falsification
- Scientific findings will not be perfect- results get checked and rechecked with further findings
- This process of correction helps make science one of the most successful areas of human endeavor
- Eg. Darwin's Theory of evolution- occurring gradually, causing small incremental changes in organisms at a relatively steady rate- Gould and Eldredge - evolution consists of long periods of stability that are punctuated by occasional instances of dramatic change – a process they called **punctuated equilibrium**

Models

- A representation of some object or event- made to better understand it
- Often used if real thing is too big, small or complex
- Used to evolve or formulate theories when direct observation and study is difficult or impossible
- Come in a variety of forms
    - Physical models

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  - Diagrams
  - Computer models
- Model Organisms- Discoveries made in them applicable to other organisms. Eg. *Escherichia coli*, yeast, *Drosophila*, *Arabidopsis* etc.

Why do scientists use MODELS?

To save time and money when testing ideas that are

- Very large or Very small
- May be inaccessible for direct visual study- e.g. center of the Earth or the surface of a distant galactic object
- Dangerous and Time-consuming

Simulations

- Imitation of a real thing or process
- Used when testing real thing is impossible- eg. study of origin of life- Miller and Urey
- Computer simulations- medical research- dummy of human body- mannequin- response to drugs and create life threatening emergencies

Virtual Testing

- Virtual = 'not real'- conceptual possessing features of the real
- Computer reconstruction and multidimensional image data- powerful visualization tool for scientists

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