UNIT 4

SCIENTIFIC MODELS, THEORIES AND LAWS

OUTLINE

- HYPOTHESIS IN SCIENCE
- SCIENTIFIC MODELS
- SCIENTIFIC THEORY
- SCIENTIFIC LAWS

OVERVIEW

- Models are of central importance in many scientific contexts.
- The centrality of models such as inflationary models in cosmology, general-circulation models of the global climate, the double-helix model of DNA, evolutionary models in biology, agent-based models in the social sciences, and general-equilibrium models.
- Scientific modeling is a research method scientist use to replicate real-world systems – whether it's a conceptual model of an atom, a physical model of a river delta, or a computer model of global climate.
- In this unit, the principles that scientists use when building models and how modeling contributes to the process of science will be discussed.

WHAT IS A HYPOTHESIS IN SCIENCE?

- A hypothesis (plural hypotheses) is a proposed explanation for an observation.
- The definition depends on the subject. In science, a hypothesis is part of the scientific method.
- It is a prediction or explanation that is tested by an experiment.
- In science, a hypothesis is part of the scientific method.
- Observations and experiments may disprove support or refute a scientific hypothesis., but can never
- entirely prove one.
- In the study of logic, a hypothesis is an if-then proposition, typically written in the form, "If X, then Y."

Cont'd

- In common usage, a hypothesis is simply a proposed explanation or prediction, which may or may not be tested.
- In science, a hypothesis proposes a relationship between factors called variables.
- A good hypothesis relates an independent variable and a dependent variable.
- The effect on the dependent variable depends on or is determined by what happens when you change the independent variable.
- While you could consider any prediction of an outcome to be a type of hypothesis, a good hypothesis is one you can test using the scientific method.

Cont’d

- In other words, you want to propose a hypothesis to use as the basis for an experiment.
- A hypothesis statement tells the world what you predict will happen in research.
- One of the most important elements of a hypothesis is that it must be able to be tested.
- Simply put, a hypothesis is an idea that can be tested based on the evidence available.
- A concept or statement must be tested to be proven credible.
- This serves as a starting point for further investigation to prove the hypothesis by applying the scientific method.
- However, there are multiple variables that can affect the results, and therefore the idea must be tested multiple times

Activity

- I guess the word hypothesis is not new to you?
- Can you explain the word hypothesis in your own words?
- Share your understanding of it with a colleague and your class.

Example of a Hypothesis

- A simple hypothesis predicts the relationship between two variables: the independent variable and the dependent variable.
- This relationship is demonstrated through these examples:
- If you increase the duration of light, (then) corn plants will grow more each day
- Drinking sugary drinks daily leads to being overweight.
- Smoking cigarettes daily leads to lung cancer.

Cont’d

- Getting at least 8 hours of sleep can make people more alert.
- Human Beings from Mars would not be able to breathe the air in Earth's atmosphere.
- Creatures found at the bottom of the ocean use anaerobic respiration rather than aerobic respiration.
- Roses watered with liquid Vitamin B grow faster than roses watered with liquid Vitamin E.
- Women taking vitamin E grow hair faster than those taking vitamin K.
- There is no relationship between smoking and lung cancer.

Cont'd

- If you drop a rock and a feather, (then) they will fall at the same rate.
- Plants need sunlight in order to live. (if sunlight, then life)
- Eating sugar gives you energy. (if sugar, then energy)
- If you turn out all the lights, you will fall asleep faster. (Think: How would you test it?)
- If you drop different objects, they will fall at the same rate.
- If you eat only fast food, then you will gain weight.

Cont'd

- If you use cruise control, then your car will get better gas mileage.
- If you apply a top coat, then your manicure will last longer.
- If you turn the lights on and off rapidly, then the bulb will burn out faster.
- The rate of corn plant growth does not depend on the duration of light.

Key Points when formulating a Hypothesis

- Does the hypothesis relate an independent and dependent variable? Can you identify the variables?
- Can you test the hypothesis? In other words, could you design an experiment that would allow you to establish or disprove a relationship between the variables?
- Would your experiment be safe and ethical?
- Is there a simpler or more precise way to state the hypothesis? If so, rewrite it.

Parts of a Hypothesis: Independent and Dependent Variables

- **Independent variable**: The variable that the research changes (for example, the weight-control medication that a certain research group gets) an independent variable stands on its own and is not changed by other variables
- **Dependent variable**: The variable that the researcher is testing and measuring in relation to the independent variable (for example, how much weight the research group actually loses) the dependent variable depends on other factors

Examples of dependent and independent variable

- The independent variable can cause a change in the dependent variable, but the dependent variable cannot cause a change in the independent variable. For example: How does the amount of makeup one applies affect how clear their skin is?
- Carb Loading and Endurance. An exercise physiologist wonders if carb loading (eating a lot of carbohydrates) the day before participating in endurance activities (such as triathlons or marathons) impacts performance. Independent variable - quantity of carbohydrates consumed within a defined timeframe dependent variable - performance in an endurance activity

Cont’d

- **Cancer Medicine.** A scientist studies the impact of a drug on cancer. She administers the drug to a research group and a placebo to a control group. independent variable - administration of the drug (such as dosage or timing) dependent variable - the drug's impact on cancer
- **Rats and Affection.** A scientist studies the impact of withholding affection from rats. One group receives a lot of affection, while the other receives none. independent variable - amount of affection dependent variable - reaction of the rats

Cont'd

- **Language Mastery.** A researcher explores whether people who already speak multiple languages learn new languages faster than people who only speak one language. Independent variable - number of languages spoken. dependent variable - amount of time to master a new language
- **Education and Earnings.** A researcher wants to know if education level impacts how much a person earns in their job. She studies the amount of education a person has in their life to their current earnings. independent variable - highest level of educational attainment dependent variable - earnings (salary or wages)

Cont’d

- **National Origin and Net Worth.** A social scientist wonders if there is an association between a person's national origin and their wealth, measured as net worth. independent variable - a person's country of origin. dependent variable - a person's financial net worth
- **Time Spent Studying and Academic Success.** An educational researcher explores whether there is a link between the amount of time someone spends studying and the grade they get in a particular class. independent variable - amount of time spent studying for a particular class dependent variable - grade in the class

Cont'd

- **Job Satisfaction and Pay.** A human resources professional wonders if how much money a person earns can impact the extent to which an individual experiences job satisfaction. independent variable - compensation (salary or wages) dependent variable - job satisfactionis the ability to state how to measure a variable in an experiment.
- For example, stating that bean growth will be measured in centimeters per week. Whatever information individuals acquire through experiments such as observations or experiences are used to describe in meaningful statement a phenomenon, object or event.

Types of Hypotheses

- Null Hypothesis and
- Alternative Hypothesis

Null hypothesis

- The null hypothesis assumes that there is no relationship between the study variables.
- For this reason, it is also known as a non-relationship hypothesis.
- This hypothesis will be accepted if the investigation shows that the working hypothesis and alternative hypotheses are not valid.
- In a scientific experiment, the null hypothesis is the proposition that there is no effect or no relationship between
- phenomena or populations.
- The null hypothesis states there is no relationship between the measured phenomenon (the dependent variable) and the independent variable.

Cont'd

- The null hypothesis is useful because it can be tested and found to be either false or true.
- If the null hypothesis is found to be false after testing, which then it implies that there is a relationship between the observed data.
- It may be easier to think of it as a nullifiable hypothesis or one that the researcher seeks to nullify.
- The null hypothesis is also known as the H0, or no-difference hypothesis.
- The null hypothesis—which assumes that there is no meaningful relationship between two variables—may be the most valuable hypothesis for the scientific method because it is the easiest to test using a statistical analysis.
- This means you can support or reject your hypothesis with a high level of confidence. Testing the null hypothesis can tell you whether your results are due to the effect of manipulating the dependent variable or due to chance.

Cont’d

- You do not need to believe that the null hypothesis is true to test it.
- On the contrary, you will likely suspect that there is a relationship between a set of variables.
- One way to prove that this is the case is to reject the null hypothesis.
- Rejecting a hypothesis does not mean an experiment was "bad" or that it didn't produce results.
- In fact, it is often one of the first steps toward further inquiry.
- To distinguish it from other hypotheses, the null hypothesis is written as H0 (which is read as “H-nought,” "H-null," or "H-zero").

Cont’d

- A significance test is used to determine the likelihood that the results supporting the null hypothesis are not due to chance.
- A confidence level of 95 percent or 99 percent is common.
- Keep in mind, even if the confidence level is high, there is still a small chance the null hypothesis is not true, perhaps because the experimenter did not account for a critical factor or because of chance.
- This is one reason why it's important to repeat experiments. The null hypothesis reflects that there will be no observed effect in our experiment.
- In a mathematical formulation of the null hypothesis, there will typically be an equal sign.

Cont’d

- This hypothesis is denoted by H0.
- A null hypothesis, denoted by H0, proposes that two factors or groups are unrelated and that there is no difference between certain characteristics of a population or process.
- You must test the likelihood of the null hypothesis, in tandem with an alternative hypothesis, in order to disprove or discredit it

Null Hypothesis Examples

- **"Hyperactivity is unrelated to eating sugar" is an example of a null hypothesis.** If the hypothesis is tested and found to be false, using statistics, then a connection between hyperactivity and sugar ingestion may be indicated. A significance test is the most common statistical test used to establish confidence in a null hypothesis.
- **Another example of a null hypothesis is "Plant growth rate is unaffected by the presence of cadmium in the soil."** A researcher could test the hypothesis by measuring the growth rate of plants grown in a medium lacking cadmium, compared with the growth rate of plants grown in mediums containing different amounts of cadmium. Disproving the null hypothesis would set the groundwork for further research into the effects of different concentrations of the element in soil.

Cont’d

- Hyperactivity is unrelated to eating sugar.
- All daisies have the same number of petals.
- The number of pets in a household is unrelated to the number of people living in it.
- A person's preference for a shirt is unrelated to its color.
- To write a null hypothesis, first start by asking a question. Rephrase that question in a form that assumes no relationship between the variables. In other words, assume a treatment has no effect. Write your hypothesis in a way that reflects this.

Cont’d

- There is no significant change in a person’s health during the times when they drink green tea only or root beer only.
- There is no significant change in an individual’s work habits whether they get eight hours or nine hours of sleep.
- There is no significant change in the growth of a plant if one uses distilled water only or vitamin-rich water only to water it.
- There is no relationship between students' hair color and their academic results.

How to State a Null Hypothesis

- One is to state it as a declarative sentence, and the other is to present it as a mathematical statement.
- The other way to state the null hypothesis is to make no assumption about the outcome of the experiment.

Cont'd

Question	Null Hypothesis
Are teens better at math than adults?	Age has no effect on mathematical ability.
Does taking aspirin every day reduce the chance of having a heart attack?	Taking aspirin daily does not affect heart attack risk
Do teens use cell phones to access the internet more than adults?	Age has no effect on how cell phones are used for internet access.
Do cats care about the color of their food?	Cats express no food preference based on color.
Does chewing willow bark relieve pain?	There is no difference in pain relief after chewing willow bark versus taking a placebo.

Why Test a Null Hypothesis?

- You may be wondering why you would want to test a hypothesis just to find it false.
- Why not just test an alternate hypothesis and find it true? The short answer is that it is part of the scientific method.
- In science, propositions are not explicitly "proven."
- Rather, science uses statistics to determine the probability that a statement is true or false.
- It turns out it is much easier to disprove a hypothesis than to positively prove one.

Developing Integrated Process Skills in Students

- In everyday life activities students use integrated process skills such as hypothesising, interpreting and experimenting.
- This means that students should develop these abilities to be able to make life easier for them.
- Students should participate actively in experiments because designing and conducting an experiment requires the use of many skills such as formulating hypothesis, controlling variables, defining operationally, interpreting data and formulating models.

Cont'd

- Also, while the null hypothesis may be simply stated, there is a good chance the alternate hypothesis is incorrect.
- For example, if your null hypothesis is that plant growth is unaffected by duration of sunlight, you could state the alternate hypothesis in several different ways.
- You could say plants are harmed by more than 12 hours of sunlight or that plants need at least three hours of sunlight, etc.
- There are clear exceptions to those alternate hypotheses, so if you test the wrong plants, you could reach the wrong conclusion.
- The null hypothesis is a general statement that can be used to develop an alternate hypothesis, which may or may not be correct.

Alternative Hypothesis

- An alternative hypothesis, denoted by H1 or HA, is a claim that is contradictory to the null hypothesis.
- Researchers will pair the alternative hypothesis with the null hypothesis in order to prove that there is no relation.
- If the null hypothesis is disproven, then the alternative hypothesis will be accepted.
- If the null hypothesis is not rejected, then the alternative hypothesis will not be accepted.
- The alternative or experimental hypothesis reflects that there will be an observed effect for our experiment.

Cont'd

- In a mathematical formulation of the alternative hypothesis, there will typically be an inequality, or not equal to symbol.
- This hypothesis is denoted by either Ha or by H1.
- The alternative hypothesis is what we are attempting to demonstrate in an indirect way by the use of our hypothesis test.
- If the null hypothesis is rejected, then we accept the alternative hypothesis.

Cont'd

- If the null hypothesis is not rejected, then we do not accept the alternative hypothesis.
- Going back to the above example of mean human body temperature, the alternative hypothesis is "The average adult human body temperature is not 98.6 degrees Fahrenheit."
- If we are studying a new treatment, then the alternative hypothesis is that our treatment does, in fact, change our subjects in a meaningful and measurable way.

Negation

- The following set of negations may help when you are forming your null and alternative hypotheses.
- Most technical papers rely on just the first formulation, even though you may see some of the others in a statistics textbook.
- Null hypothesis: “x is equal to y.” Alternative hypothesis “x is not equal to y.”
- Null hypothesis: “x is at least y.” Alternative hypothesis “x is less than y.”
- Null hypothesis: “x is at most y.” Alternative hypothesis “x is greater than y.”

How to Write a Hypothesis/Steps on how to Write a Hypothesis

- Ask a question.
- Gather preliminary research.
- Formulate an answer.
- Write a hypothesis.
- Refine your hypothesis.
- Create a null hypothesis.

Ask a Question

- In the scientific method, the first step is to ask a question. Frame this question using the classic six: who, what, where, when, why, or how. Sample questions might include:
  - How long does it take carrots to grow?
  - Why does the sky get darker earlier in winter?
  - What happened to the dinosaurs?
  - How did we evolve from monkeys?
  - Why are students antsier on Friday afternoon?
  - How does sleep affect motivation?

Gather Preliminary Research

- It's time to collect data. This will come in the form of case studies and academic journals, as well as your own experiments and observations.
- Remember, it's important to explore your question from all sides.
- Don't let conflicting research deter you. You might come upon many naysayers as you gather background information. That doesn't invalidate your hypothesis.
- In fact, you can use their findings as potential rebuttals and frame your study in such a way as to address these concerns.
- For example, if you are looking at the question: "How does sleep affect motivation?", you might find studies with conflicting research about eight hours vs. six hours of sleep.
- You can use these conflicting points to help to guide the creation of your hypothesis.

Formulate an Answer to Your Question

- After completing all your research, think about how you will answer your question and defend your position.
- For example, say the question you posed was: How does sleep affect motivation? As you start to collect basic observations and information, you'll find that a lack of sleep creates a negative impact on learning.
- It decreases thought processes and makes it harder to learn anything new.
- Therefore, when you are tired, it's harder to learn and requires more effort. Since it is harder, you can be less motivated to do it.

Write a Hypothesis

- With the answer to your question at the ready, it's time to formulate your hypothesis. To write a good hypothesis, it should include:
  - Relevant variables
  - Predicted outcome
  - Who/what is being studied?
- Remember that your hypothesis needs to be a statement, not a question. It's an idea, proposal or prediction.

Cont’d

- For example, a research hypothesis is formatted in an if/then statement: If a person gets less than eight hours of sleep, then they will be less motivated at work or school. This statement shows you:
  - who is being studied - a person?
  - the variables - sleep and motivation
  - your prediction - less sleep means less motivation

Refine Your Hypothesis

- Make sure your hypothesis is to the point and testable. Similarly, it can be refined in a variety of ways. All the terms that you use must be defined clearly and contain the following elements.
  - The required variables
  - The group that is being studied
  - The predicted outcome of the analysis

Create or compose your Hypothesis in three different Ways

- You can formulate a simple prediction in the form of if…then to identify the variables.
- The beginning of the sentence should state the independent variable and dependent variable at the end of the sentence.
- In academic research, a hypothesis is commonly phrased in terms of defining relations or showing effects.
- Here you need to state the relationship between variables.
- If you are making a comparison, your hypothesis should state what difference you expect.
- Depending on your study, you may need to perform some statistical analysis on the data you collect.

Cont'd

- When forming your hypothesis statement using the scientific method, it's important to know the difference between a null hypothesis vs. the alternative hypothesis, and how to create a null hypothesis.
- A null hypothesis, often denoted as H0, posits that there is no apparent difference or that there is no evidence to support a difference.
- Using the motivation example above, the null hypothesis would be that sleep hours have no effect on motivation.
- An alternative hypothesis, often denoted as H1, states that there is a statistically significant difference, or there is evidence to support such a difference.
- Going back to the same carrot example, the alternative hypothesis is that a person getting six hours of sleep has less motivation than someone getting eight hours of sleep.

Good and Bad Hypothesis Examples

Question	Hypothesis
How long does it take carrots to grow?	**Good**: If we plant carrots deep in the soil, it will take them longer to grow than in shallow soil. **Bad:** You can plant carrots deep in the soil. (There's no predicted outcome.)
Why does the sky get darker earlier in winter?	**Good**: The Earth's rotation affects the number of daylight hours. **Bad**: The sun goes down. (This doesn't clarify variables or what will be studied.)
What happened to the dinosaurs?	**Good:** If we study marine fossils found in the Arctic, we will see that dinosaurs disappeared when a comet hit the Earth. **Bad**: Extinction happened thousands of years ago. (This does not name what is being studied nor present clear variables for studying dinosaur history.)

Cont'd

How did we evolve from monkeys?	**Good**: Human beings are not descended from apes, but share a common ancestor with them. **Bad**: Human evolution is long. (This does not present clear variables to be studied or a prediction to be tested.)
Why are students antsier on Friday afternoon?	**Good**: Students are anticipating the coming of the weekend, making them antsier on Friday afternoon. **Bad**: Students have bad behavior. (This isn't showing what is being tested or clear variables.)

Cont'd

How does sleep affect motivation?	**Good**: If a person gets less than eight hours of sleep, then they will be less motivated at work or school. **Bad**: Sleep is important. (While this might be true, it's not setting the variables for the study.)
Why do IEP accommodations work in schools?	**Good**: If a student gets accommodations for their learning disability, then they will perform better in school. **Bad**: Accommodations help students. (Again, while this might be true, it's not providing what is being studied or the variables.)

What if the Hypothesis is incorrect?

- It's not wrong or bad if the hypothesis is not supported or is incorrect.
- Actually, this outcome may tell you more about a relationship between the variables than if the hypothesis is supported.
- You may intentionally write your hypothesis as a null hypothesis or no-difference hypothesis to establish a relationship between the variables.

Differences between null and Alternative Hypothesis

- A null hypothesis is a statement, in which there is no relationship between two variables. An alternative hypothesis is a statement; that is simply the inverse of the null hypothesis, i.e. there is some statistical significance between two measured phenomenon.
- A null hypothesis is what, the researcher tries to disprove whereas an alternative hypothesis is what the researcher wants to prove.
- A null hypothesis represents, no observed effect whereas an alternative hypothesis reflects, some observed effect.
- If the null hypothesis is accepted, no changes will be made in the opinions or actions. Conversely, if the alternative hypothesis is accepted, it will result in the changes in the opinions or actions.

Cont'd

- As null hypothesis refers to population parameter, the testing is indirect and implicit. On the other hand, the alternative hypothesis indicates sample statistic, wherein, the testing is direct and explicit.
- A null hypothesis is labelled as H0 (H-zero) while an alternative hypothesis is represented by H1 (H-one).
- The mathematical formulation of a null hypothesis is an equal sign but for an alternative hypothesis is not equal to sign.
- In null hypothesis, the observations are the outcome of chance whereas, in the case of the alternative hypothesis, the observations are an outcome of real effect.

Definitions of scientific models

- In science, a model is a representation of an idea, an object or even a process or a system that is used to describe and explain phenomena that cannot be experienced directly.
- A scientific model can also be a representation of a particular phenomenon in the world using something else to represent it, making it easier to understand.
- Models are central to what scientists do, both in their research as well as when communicating their explanations.
- Models are a mentally visual way of linking theory with experiment, and they guide research by being simplified representations of an imagined reality that enable predictions to be developed and tested by experiment.

Cont’d

- A scientific model could be a diagram or picture, a physical model like an aircraft model kit you got when you were young, a computer program, or set of complex mathematics that describes a situation.
- Whatever it is, the goal is to make the particular thing you are modeling easier to understand.
- When we do that, we're able to use it to predict what will happen in the future.
- For example, predicting what will happen as our climate changes would be easy if we could make a fully accurate model of the atmosphere.

Cont’d

- Scientists build models to explain how aspects of the real-world work.
- A scientific model consists of ideas and concepts, and includes some kind of mechanism.
- Many models are built and investigated using mathematics, and computers allow very complex mathematical models.
- Often, there are competing models for the same phenomenon.

Characteristics of scientific models

- A good scientific model should include a mechanism. When scientists construct a model, they are hypothesising that some poorly understood aspect of the real world can be compared (at least in some respects) to a mechanism that is well-understood.
- Every scientific model must be refutable or falsifiable – that is, there must be a way of testing whether it is false.
- A scientific model must be able to generate predictions. It will be accepted by the scientific community only if its predictions stand up against data from the real world.

Cont’d

- New models are more likely to succeed if they dovetail with existing scientific models. In fact, successful models often reveal that phenomena that were previously thought to be isolated are really connected.
- The only objective characteristic that a scientific model is a "good scientific model" is that it represents the true reality without leaving room for error between theory and experimentation.
- Models are also used to make predictions about how the behavior might change in the future or under new conditions. In order to be useful in this way, the scientific model must include all the known components of the system or phenomenon under investigation. It must also show the relationships between those components or how they interact, and it must account for and explain all observations.

Types of scientific model

- Scale models.
- Analogical models.
- Idealized models.
- Toy models.
- Minimal models.
- Phenomenological models.
- Exploratory models.
- Models of data.
- Visual Models/Conceptual models.
- Mathematical/Computer Models
- Physical models

Scale models.

- Some models are down-sized or enlarged copies of their target systems.
- A typical example is a small wooden car that is put into a wind tunnel to explore the actual car's aerodynamic properties.
- The intuition is that a scale model is a naturalistic replica or a truthful mirror image of the target; for this reason, scale models are sometimes also referred to as "true models".
- However, there is no such thing as a perfectly faithful scale model; faithfulness is always restricted to some respects.
- The wooden scale model of the car provides a faithful portrayal of the car's shape but not of its material.

Cont'd

- And even in the respects in which a model is a faithful representation, the relation between model-properties and target-properties is usually not straightforward.
- When engineers use, say, a 1:100 scale model of a ship to investigate the resistance that an actual ship experiences when moving through the water, they cannot simply measure the resistance the model experiences and then multiply it with the scale.
- In fact, the resistance faced by the model does not translate into the resistance faced by the actual ship in a straightforward manner (that is, one cannot simply scale the water resistance with the scale of the model: the real ship need not have one hundred times the water resistance of its 1:100 model).

Analogical models

- Analog models represent processes using elements that are, to some degree, analogous to those in the actual process.
- Standard examples of analogical models include the billiard ball model of a gas, the hydraulic model of an economic system, and the dumb hole model of a black hole.
- At the most basic level, two things are analogous if there are certain relevant similarities between them.
- In a classic text, Hesse (1963) distinguishes different types of analogies according to the kinds of similarity relations into which two objects enter.
- A simple type of analogy is one that is based on shared properties.

Cont’d

- There is an analogy between the earth and the moon based on the fact that both are large, solid, opaque, spherical bodies that receive heat and light from the sun, revolve around their axes, and gravitate towards other bodies.
- But sameness of properties is not a necessary condition. An analogy between two objects can also be based on relevant similarities between their properties.
- In this more liberal sense, we can say that there is an analogy between sound and light because echoes are similar to reflections, loudness to brightness, pitch to color, detectability by the ear to detectability by the eye, and so on.
- Analogies can also be based on the sameness or resemblance of relations between parts of two systems rather than on their monadic properties.

Cont'd

- It is in this sense that the relation of a father to his children is asserted to be analogous to the relation of the state to its citizens.
- The analogies mentioned so far have been what Hesse calls "material analogies".
- We obtain a more formal notion of analogy when we abstract from the concrete features of the systems and only focus on their formal set-up.
- What the analogue model then shares with its target is not a set of features, but the same pattern of abstract relationships (i.e., the same structure, where structure is understood in a formal sense).

Idealized models

- Idealized models are models that involve a deliberate simplification or distortion of something complicated with the objective of making it more tractable or understandable.
- Frictionless planes, point masses, completely isolated systems, omniscient and fully rational agents, and markets in perfect equilibrium are well-known examples.
- Idealizations are a crucial means for science to cope with systems that are too difficult to study in their full complexity.
- What does a model involving distortions tell us about reality?
- One formulated theory which understands idealizations as ideal limits: imagine a series of refinements of the actual situation which approach the postulated limit, and then require that the closer the properties of a system come to the ideal limit, the closer its behavior has to come to the behavior of the system at the limit (monotonicity).

Toy models

- Toy models are extremely simplified and strongly distorted renderings of their targets, and often only represent a small number of causal or explanatory factors.
- Typical examples are the Lotka–Volterra model in population ecology and the Schelling model of segregation in the social sciences.
- Toy models usually do not perform well in terms of prediction and empirical adequacy, and they seem to serve other epistemic goals.
- This raises the question whether they should be regarded as representational at all. Some toy models are characterized as "caricatures".

Cont’d

- Caricature models isolate a small number of salient characteristics of a system and distort them into an extreme case.
- A classic example model of the car market (“the market for lemons”), which explains the difference in price between new and used cars solely in terms of asymmetric information, thereby disregarding all other factors that may influence the prices of cars.
- However, it is controversial whether such highly idealized models can still be regarded as informative representations of their target systems.

Minimal models

- Minimal models are closely related to toy models in that they are also highly simplified.
- They are so simplified that some argue that they are non-representational: they lack any similarity, isomorphism, or resemblance relation to the world (Batterman and Rice 2014).
- It has been argued that many economic models are of this kind (Grüne-Yanoff 2009). Minimal economic models are also unconstrained by natural laws, and do not isolate any real factors (ibid.).
- And yet, minimal models help us to learn something about the world in the sense that they function as surrogates for a real system: scientists can study the model to learn something about the target.

Cont’d

- It is, however, controversial whether minimal models can assist scientists in learning something about the world if they do not represent anything (Fumagalli 2016).
- Minimal models that purportedly lack any similarity or representation are also used in different parts of physics to explain the macro-scale behavior of various systems whose micro-scale behavior is extremely diverse (Batterman and Rice 2014; Rice 2018, 2019; Shech 2018).
- Typical examples are the features of phase transitions and the flow of fluids.
- Proponents of minimal models argue that what provides an explanation of the macro-scale behavior of a system in these cases is not a feature that system and model have in common, but the fact that the system and the model belong to the same universality class (a class of models that exhibit the same limiting behavior even though they show very different behavior at finite scales

Phenomenological models

- Phenomenological models have been defined in different, although related, ways.
- A common definition takes them to be models that only represent observable properties of their targets and refrain from postulating hidden mechanisms and the like (Bokulich 2011).
- Another approach, due to McMullin (1968), defines phenomenological models as models that are independent of theories. This, however, seems to be too strong.
- Many phenomenological models, while failing to be derivable from a theory, incorporate principles and laws associated with theories.
- The liquid-drop model of the atomic nucleus, for instance, portrays the nucleus as a liquid drop and describes it as having several properties (surface tension and charge, among others) originating in different theories (hydrodynamics and electrodynamics, respectively).

Cont’d

- Certain aspects of these theories—although usually not the full theories—are then used to determine both the static and dynamical properties of the nucleus.
- Finally, it is tempting to identify phenomenological models with models of a phenomenon.
- Here, “phenomenon” is an umbrella term covering all relatively stable and general features of the world that are interesting from a scientific point of view.
- The weakening of sound as a function of the distance to the source, the decay of alpha particles, the chemical reactions that take place when a piece of limestone dissolves in an acid, the growth of a population of rabbits, and the dependence of house prices on the base rate of the Federal Reserve are phenomena in this sense.

Exploratory models

- Exploratory models are models which are not proposed in the first place to learn something about a specific target system or a particular experimentally established phenomenon.
- Exploratory models function as the starting point of further explorations in which the model is modified and refined.
- Gelfert (2016) points out that exploratory models can provide proofs-of-principle and suggest how-possibly explanations (2016: Ch. 4).
- As an example, Gelfert mentions early models in theoretical ecology, such as the Lotka–Volterra model of predator–prey interaction, which mimic the qualitative behavior of speed-up and slow-down in population growth in an environment with limited resources (2016: 80).
- Such models do not give an accurate account of the behavior of any actual population, but they provide the starting point for the development of more realistic models. Massimi (2019) notes that exploratory models provide modal knowledge.

Models of data

- A model of data (sometimes also “data model”) is a corrected, rectified, regimented, and in many instances idealized version of the data we gain from immediate observation, the so-called raw data (Suppes 1962).
- Characteristically, one first eliminates errors (e.g., removes points from the record that are due to faulty observation) and then presents the data in a “neat” way, for instance by drawing a smooth curve through a set of points.
- These two steps are commonly referred to as “data reduction” and “curve fitting”.
- When we investigate, for instance, the trajectory of a certain planet, we first eliminate points that are fallacious from the observation records and then fit a smooth curve to the remaining ones.
- Models of data play a crucial role in confirming theories because it is the model of data, and not the often messy and complex raw data, that theories are tested against.

Cont’d

- The construction of a model of data can be extremely complicated.
- It requires sophisticated statistical techniques and raises serious methodological as well as philosophical questions.
- How do we decide which points on the record need to be removed? And given a clean set of data, what curve do we fit to it?
- The gathering, processing, dissemination, analysis, interpretation, and storage of data raise many important questions beyond the relatively narrow issues pertaining to models of data.
- Leonelli (2016, 2019) investigates the status of data in science, argues that data should be defined not by their provenance but by their evidential function, and studies how data travel between different contexts.

Visual Models/Conceptual models

- Conceptual models make comparisons with familiar things to help illustrate or explain an idea. Conceptual models can also be a system of ideas.
- The classification system used to classify living things is an example of a conceptual model.
- In the classification system, scientists group organisms by similarities.
- Another example of a conceptual model is the Bohr Model of an atom, in which electrons orbiting the nucleus of an atom the way that planets orbit the sun.
- The conceptual model provides a concept of how the components of an atom are arranged, implying a similarity of the forces acting between those components.
- It is important to note that the conceptual model is not necessarily correct or accurate but is an easy way to think about the parts of an atom.

Cont’d

- Visual models are things like flowcharts, pictures, and diagrams that help us educate each other.
- They are the ones non-scientists have most experience with. In an office you might create a flowchart that describes the work that you do.
- Maybe orders come in by phone, and that information gets transferred to both the warehouse and the membership department.
- If you include every input and output, that flowchart is an example of a visual model. Conceptual models tie together many ideas to explain a phenomenon or event. In science, visual models are often useful as educational tools, say in a classroom or from a scientist to a colleague.
- For example, a visual model can show the main processes that affect what the atmosphere is made of. No matter how clever and educated you might be, diagrams are extremely helpful in explaining how the world works.

Mathematical/Computer Models

- A mathematical model is made up of mathematical equations and data.
- Simple mathematical models allow you to calculate things, such as how many miles per hour a car will go.
- Mathematical models are sets of equations that take into account many factors to represent a phenomenon.
- Other mathematical models are so complex that computer software is needed to create them.
- Computer models are helpful in modeling events that take a long time, such as the movement of the tectonic plates.

Cont’d

- They are also just as helpful in modeling events that happen too quickly to see, such as predicting earthquakes.
- Computers also model motions and positions of things that would take hours or days to calculate by hand or through the use of a calculator.
- Scientist using computer models to help predict weather based on the motion of air currents in the atmosphere is an example of using computer models to predict the effect of different systems or forces.

Physical models

- Models that you can see and touch are called physical models.
- Physical models show how parts relate to one another.
- They can also be used to show how things appear when they change position or how they react when outside forces act on them.
- Examples include a model of the solar system, a globe of the Earth, or a model of the human torso.
- Physical models are smaller and simpler representations of the thing being studied.

Cont’d

- A globe or a map is a physical model of a portion or all of Earth.
- Some models are physical objects. Such models are commonly referred to as “material models”.
- Standard examples of models of this kind are scale models of objects like bridges and ships, Watson and Crick’s metal model of DNA (Schaffner 1969), Phillips and Newlyn’s hydraulic model of an economy (Morgan and Boumans 2004), the US Army Corps of Engineers’ model of the San Francisco Bay (Weisberg 2013), Kendrew’s plasticine model of myoglobin (Frigg and Nguyen 2016), and model organisms in the life sciences (Leonelli and Ankeny 2012; Leonelli 2010; Levy and Currie 2015).

Cont'd

- All these are material objects that serve as models.
- Material models do not give rise to ontological difficulties over and above the well-known problems in connection with objects that metaphysicians deal with, for instance concerning the nature of properties, the identity of objects, parts and wholes, and so on.
- However, many models are not material models.
- The Bohr model of the atom, a frictionless pendulum, or an isolated population, for instance, are in the scientist's mind rather than in the laboratory and they do not have to be physically realized and experimented upon to serve as models.
- These "non-physical" models raise serious ontological questions, and how they are best analyzed is debated controversially.

Why models are needed/roles of models

- Models are useful tools in learning science which can be used to improve explanations, generate discussion, make predictions, provide visual representations of abstract concepts and generate mental models (Treagust, Chittleborough and Mamiala, 2003).
- Models can play a significant epistemological and pedagogical role by providing learning opportunities. As students use models discerningly, appreciating their role, purpose and limitations, links are formed between the model and the target, and each learner constructs a personal mental model for the concept.
- Models are central to the process of knowledge-building in science and demonstrate how science knowledge is tentative.

Cont'd

- Model provide a way of explaining complex data to presenting as a hypothesis. There may be more than one model proposed by scientists to explain or predict what might happen in particular circumstances. Often scientists will argue about the 'rightness' of their model, and in the process, the model will evolve or be rejected.
- Many times, the system or object of a scientist's interest may be too small to be observed directly, like parts of atoms. Other objects may be inaccessible for direct visual study, like the center of the Earth or the surface of a distant galactic object. So, a scientific model can be scaled-down version or a scaled-up version of a natural object or system. New scientific discoveries and understanding frequently depend upon scientists developing scientific models and interacting with them.

Cont'd

- Scientific models are representations of objects, systems or events and are used as tools for understanding the natural world. Models use familiar objects to represent unfamiliar things.
- Models can help you visualize, or picture in your mind, something that is difficult to see or understand.
- Models can help scientists communicate their ideas, understand processes, and make predictions.
- One of the main reasons why models play such an important role in science is that they perform a number of cognitive functions. For example, models are vehicles for learning about the world.

Cont’d

- Significant parts of scientific investigation are carried out on models rather than on reality itself because by studying a model we can discover features of, and ascertain facts about, the system the model stands for: models allow for “surrogative reasoning” (Swoyer 1991).
- Models allow us to investigate complex things that we don’t understand well by using our knowledge of simpler things. Once a model finds supporting evidence and is accepted, it can be confidently used to make reliable predictions about the phenomenon it represents. Finding a model that fits a phenomenon is what we mean by “explaining” or “understanding” that phenomenon.
- Once models are accepted, they allow scientists to communicate and understand each other because they provide a common, shared mental picture of a phenomenon.

What models can represent?

Models can represent . . .	Example
objects that are too small to see	Model of an atom or a cell
objects that are too big to see	Model of the planets
objects that no longer exist	Model of a dinosaur
objects that have not yet been invented	Prototype models such as a model of a robot
events that occur too slowly to see	Model of mountain formation
events that occur too fast to see	Model to predict an earthquake
events that have yet to happen	Models of weather systems

How do you decide whether a model is "right"?

- Can the model explain all or most of the observations?
- Can the model be used to predict the happenings of the system or event if it is manipulated in a specific way? For example, if a new piece of evidence is found, will your model still be the most likely story of what happened? Being able to correctly predict experimental outcomes is a powerful way of testing some kinds of models.
- Is the model consistent with other ideas we have about how the world works? Any models involving an invisible alien man who can do magic are automatically rejected on the basis of their absurdity:
- Is the model "acceptable". And acceptability is based on a model’s ability to do the three things outlined above: explain, predict, and be consistent with another knowledge. Second, more than one model may be an acceptable explanation for the same phenomenon. It is not always possible to exclude all but one model — and also not always desirable.

Advantages of Science Models

- **Models are used for communication**—Models are used to communicate observations and ideas to other people. Models help people visualize ideas or abstract concepts.
- **Models are just the right size**—Models are used to represent things that are very small or very large. Models can help you picture things in your mind.
- **Models are used to make and test predictions**—Models can be used to make predictions. When scientists develop a hypothesis, they can use models to test and prove or disprove their hypothesis. Engineers can use models to predict how their inventions will perform.
- **Models save time, money, and lives**—Working and testing with models can be safer, quicker, and less expensive than using the real thing.
- **Models build scientific knowledge—**Models can be used to help illustrate and explain scientific theories.

Limitations of science Models

- **Details**: Models cannot include all the details of the objects that they represent. For example, maps cannot include all the details of the features of the earth such as mountains, valleys, etc.
- **Approximations**: Most models include some approximations as a convenient way to describe something that happens in nature. These approximations are not exact, so predictions based on them tend to be a little bit different from what you. Models do not behave exactly like the things they represent.
- **Accuracy**: In order to make models simplistic enough to communicate ideas some accuracy is lost. For example, ball and stick models of atoms do not show all the details that scientists know about the structure of the atom.
- **Since models are simpler than real objects or systems, they have limitations**. A model deals with only a portion of a system. It may not predict the behavior of the real system very accurately.

How can we use models in teaching science?

- Planning for engagement with important science ideas. Teachers unpack standards to identify learning targets, an anchoring phenomenon, and a driving question that orients students to some interesting aspect of the anchoring phenomenon.
- The second stage is eliciting student ideas. Teachers introduce the anchoring phenomenon and driving question to the students at the beginning of this stage. Students develop initial hypotheses and initial models based on observations and shared ideas.

Cont'd

- The third stage is supporting ongoing changes in thinking. Students, in this stage, will have opportunities to reconstruct, test, evaluate, and revise their initial models based on the results of scientific inquiry (e.g., observations, experiments, or discussions) and engagement with many other science practices (e.g., engaging in argument from evidence).
- Finally, the fourth stage is pressing for evidence-based explanations. In this last stage, students finalize their models by considering all they have learned across the unit through engaging in investigations, activities, opportunities to read relevant texts, and working collectively as a class to build general agreement about their models.

SCIENTIFIC THEORY

- A scientific theory is an explanation of an aspect of the natural world and universe that can be repeatedly tested and verified in accordance with the scientific method, using accepted protocols of observation, measurement, and evaluation of results.
- Theories are broad explanations for a wide range of phenomena.
- They are concise (i.e., generally don't have a long list of exceptions and special rules), coherent, systematic, predictive, and broadly applicable.
- In fact, theories often integrate and generalize many hypotheses.

Cont'd

- For example, the theory of natural selection broadly applies to all populations with some form of inheritance, variation, and differential reproductive success — whether that population is composed of alpine butterflies, fruit flies on a tropical island, a new form of life discovered on Mars, or even bits in a computer's memory.
- This theory helps us understand a wide range of observations (from the rise of antibiotic-resistant bacteria to the physical match between pollinators and their preferred flowers), makes predictions in new situations (e.g., that treating AIDS patients with a cocktail of medications should slow the evolution of the virus), and has proven itself time and time again in thousands of experiments and observational studies.

The United States National Academy of Sciences defines scientific theories as follows:

- The formal scientific definition of theory is quite different from the everyday meaning of the word.
- It refers to a comprehensive explanation of some aspect of nature that is supported by a vast body of evidence.
- Many scientific theories are so well established that no new evidence is likely to alter them substantially.
- For example, no new evidence will demonstrate that the Earth does not orbit around the Sun (heliocentric theory), or that living things are not made of cells (cell theory), that matter is not composed of atoms, or that the surface of the Earth is not divided into solid plates that have moved over geological timescales (the theory of plate tectonics)...
- One of the most useful properties of scientific theories is that they can be used to make predictions about natural events or phenomena that have not yet been observed.

The American Association for the Advancement of Science:

- A scientific theory is a well-substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment.
- Such fact-supported theories are not "guesses" but reliable accounts of the real world.
- The theory of biological evolution is more than "just a theory".
- It is as factual an explanation of the universe as the atomic theory of matter or the germ theory of disease.
- Our understanding of gravity is still a work in progress. But the phenomenon of gravity, like evolution, is an accepted fact.

Cont'd

- A theory is a scientifically acceptable general principle that can explain a phenomenon.
- Oxford dictionary defines it as "a supposition or a system of ideas intended to explain something, especially one based on general principles independent of the thing to be explained" while American Heritage dictionary defines it as a "set of statements or principles devised to explain a group of facts or phenomena, especially one that has been repeatedly tested or is widely accepted and can be used to make predictions about natural phenomena".
- Thus, a theory always explains a specific phenomenon.
- Moreover, a theory stems from a hypothesis, which is proven with valid evidence.

Cont'd

- We mostly encounter theories in the field of science.
- Quantum theory, theory of evolution, theory of general relativity, theory of special relativity are some examples of scientific theory.
- In addition, there are various theories such as political theories and philosophical theories.
- However, it also important to note that theory may not be universally accepted.
- When new evidence comes into the light with the advancement of technology and passage of time, scientists sometimes revise or replace theories.

Cont'd

- A scientific theory differs from a scientific fact or scientific law in that a theory explains "why" or "how": a fact is a simple, basic observation, whereas a law is a statement (often a mathematical equation) about a relationship between facts.
- For example, Newton's Law of Gravity is a mathematical equation that can be used to predict the attraction between bodies, but it is not a theory to explain how gravity works.
- Research has shown wrote that "...facts and theories are different things, not rungs in a hierarchy of increasing certainty.
- Facts are the world's data.
- Theories are structures of ideas that explain and interpret facts."

Cont’d

- The strength of a scientific theory is related to the diversity of phenomena it can explain and its simplicity.
- As additional scientific evidence is gathered, a scientific theory may be modified and ultimately rejected if it cannot be made to fit the new findings; in such circumstances, a more accurate theory is then required.
- Some theories are so well-established that they are unlikely ever to be fundamentally changed (for example, scientific theories such as evolution, heliocentric theory, cell theory, theory of plate tectonics, germ theory of disease, etc.). In certain cases, a scientific theory or scientific law that fails to fit all data can still be useful (due to its simplicity) as an approximation under specific conditions.

Cont’d

- An example is Newton's laws of motion, which are a highly accurate approximation to special relativity at velocities that are small relative to the speed of light.
- Scientific theories are testable and make falsifiable predictions.
- They describe the causes of a particular natural phenomenon and are used to explain and predict aspects of the physical universe or specific areas of inquiry (for example, electricity, chemistry, and astronomy).
- As with other forms of scientific knowledge, scientific theories are both deductive and inductive, aiming for predictive and explanatory power.
- Scientists use theories to further scientific knowledge, as well as to facilitate advances in technology or medicine.

Types of Science theory

- **Constructive theories** are constructive models for phenomena: for example, kinetic theory.
- **Principle theories** are empirical generalisations such as Newton's laws of motion.

Characteristics of Science theory

- It makes falsifiable predictions with consistent accuracy across a broad area of scientific inquiry (such as mechanics).
- It is well-supported by many independent strands of evidence, rather than a single foundation.
- It is consistent with preexisting experimental results and at least as accurate in its predictions as are any preexisting theories.
- It can be subjected to minor adaptations to account for new data that do not fit it perfectly, as they are discovered, thus increasing its predictive capability over time.
- It is among the most parsimonious explanations, economical in the use of proposed entities or explanatory steps as per Occam's razor. This is because for each accepted explanation of a phenomenon, there may be an extremely large, perhaps even incomprehensible, number of possible and more complex alternatives, because one can always burden failing explanations with ad hoc hypotheses to prevent them from being falsified; therefore, simpler theories are preferable to more complex ones because they are more testable.

Theories and laws

- Both scientific laws and scientific theories are produced from the scientific method through the formation and testing of hypotheses, and can predict the behavior of the natural world.
- Both are typically well-supported by observations and/or experimental evidence.
- However, scientific laws are descriptive accounts of how nature will behave under certain conditions.
- Scientific theories are broader in scope, and give overarching explanations of how nature works and why it exhibits certain characteristics.
- Theories are supported by evidence from many different sources, and may contain one or several laws.

Cont’d

- A common misconception is that scientific theories are rudimentary ideas that will eventually graduate into scientific laws when enough data and evidence have been accumulated.
- A theory does not change into a scientific law with the accumulation of new or better evidence.
- A theory will always remain a theory; a law will always remain a law. Both theories and laws could potentially be falsified by countervailing evidence.
- Theories and laws are also distinct from hypotheses.
- Unlike hypotheses, theories and laws may be simply referred to as scientific fact.
- However, in science, theories are different from facts even when they are well supported. For example, evolution is both a theory and a fact.

Assumptions in formulating theories

- An assumption (or axiom) is a statement that is accepted without evidence.
- For example, assumptions can be used as premises in a logical argument. Isaac Asimov described assumptions as follows: ...it is incorrect to speak of an assumption as either true or false, since there is no way of proving it to be either (If there were, it would no longer be an assumption).
- It is better to consider assumptions as either useful or useless, depending on whether deductions made from them corresponded to reality...Since we must start somewhere, we must have assumptions, but at least let us have as few assumptions as possible.

Cont'd

- Certain assumptions are necessary for all empirical claims (e.g. the assumption that reality exists).
- However, theories do not generally make assumptions in the conventional sense (statements accepted without evidence).
- While assumptions are often incorporated during the formation of new theories, these are either supported by evidence (such as from previously existing theories) or the evidence is produced in the course of validating the theory.
- This may be as simple as observing that the theory makes accurate predictions, which is evidence that any assumptions made at the outset are correct or approximately correct under the conditions tested.

Cont’d

- Conventional assumptions, without evidence, may be used if the theory is only intended to apply when the assumption is valid (or approximately valid).
- For example, the special theory of relativity assumes an inertial frame of reference.
- The theory makes accurate predictions when the assumption isvalid, and does not make accurate predictions when the assumption is not valid.
- Such assumptions are often the point with which older theories are succeeded by new ones (the general theory of relativity works in non-inertial reference frames as well).

Examples of theories

- **Biology**: cell theory, theory of evolution (modern evolutionary synthesis), abiogenesis, germ theory, particulate inheritance theory, dual inheritance theory
- **Chemistry**: collision theory, kinetic theory of gases, Lewis theory, molecular theory, molecular orbital theory, transition state theory, valence bond theory
- **Physics**: atomic theory, Big Bang theory, Dynamo theory, perturbation theory, theory of relativity (successor to classical mechanics), quantum field theory
- **Earth Science**: Climate change theory (from climatology),[58] plate tectonics theory (from geology), theories of the origin of the Moon, theories for the Moon illusion
- **Astronomy**: Self-gravitating system, Stellar evolution, solar nebular model, stellar nucleosynthesis

Superseded Theories

- A superseded theory, or obsolete scientific theory is a theory that was once commonly accepted, but for a given reason is no longer considered the most complete description of reality by mainstream science.
- It can also refer to a falsifiable theory which has been shown to be false. Giraffes, shown in Figure below, are often used in the explanation of Lamarck's superseded theory of evolution.
- In Lamarckism, a giraffe lengthens its neck over the course of its life in order to, for example, reach higher leaves.
- That giraffe will then have offspring with longer necks.
- The theory has been superseded by the understanding of natural selection on populations of organisms as the main means of evolution (Darwin's theory of evolution by natural selection), not physical changes to a single organism over its lifetime.

Characteristics of scientific theories

- It must be easy to obtain confirmations, or verifications, for nearly every theory—if we look for confirmations.
- Every "good" scientific theory is a prohibition: it forbids certain things to happen. The more a theory forbids, the better it is.
- A theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory (as people often think) but a vice. Every genuine test of a theory is an attempt to falsify it, or to refute it. Testability is falsifiability; but there are degrees of testability: some theories are more testable, more exposed to refutation, than others; they take, as it were, greater risks.

Cont'd

- Good theories consist of just one problem-solving strategy, or a small family of problem-solving strategies, that can be applied to a wide range of problems.
- Because a theory presents a new way of looking at the world, it must lead us to ask new questions, and so to embark on new and fruitful lines of inquiry.
- A good theory should be productive; it should raise new questions and presume those questions can be answered without giving up its problem-solving strategies.

SCIENTIFIC LAWS

- Science is present everywhere around us.
- Being the essential element of life, the basic knowledge of science is imperative for every individual.
- Science is based on laws, theories, facts, research and hypotheses.
- In other words, we sometimes refer to science as the way of pursuing knowledge and not merely knowledge.
- Deeply associated with science are the scientific laws that are derived by continuous experiments and observations on a particular subject.
- As it forms one of the major parts of learning Science, it is essential to know about the Important Scientific Laws.

Cont’d

- Some terms related to scientific law are 'hypothesis' and 'theory'. However, a scientific law is different from a hypothesis or a theory.
- The main difference is that a scientific law has been tested more than the two - it's called being empirically tested.
- But another important difference is that a hypothesis is an explanation of an observation found in nature, while a law is based on observation only.
- In other words, the hypothesis is the why, while the law is the what.

Definition of Scientific Laws

- To begin with, scientific laws or simply the laws of science are mere statements that are deduced by continuous and repeated experiments as well as observations which are used commonly to chronicle or foresee a natural situation.
- A scientific law is a statement that describes an observable occurrence in nature that appears too always to be true.
- The term law is of broad spectrum- i.e., used in physics, chemistry and biology alike.
- Usually, scientists use data to develop laws. However, it may or may not be based on empirical evidence.

Cont’d

- But what is an observable occurrence? Well, it's something that can be seen by anyone and happens with no intervention by man.
- In science, sometimes a law is called a 'principle'.
- The law or principle may describe only the occurrence, or it may describe the occurrence and predict it as well.
- However, a law does not make explanations about the natural occurrence.
- Scientific laws are similar to scientific theories, in that they are principles which can be used to predict the behavior of the natural world

Cont'd

- Both scientific laws and scientific theories are typically well-supported by observations and/or experimental evidence.
- Usually, scientific laws provide rules for how nature will behave under certain conditions.
- Scientific theories are more overarching explanations of how nature works and why it exhibits certain characteristics.
- A law can usually be formulated as one or several statements or equations, so that it can predict the outcome of an experiment.
- Laws differ from hypotheses and postulates, which are proposed during the scientific process before and during validation by experiment and observation.

Cont'd

- Hypotheses and postulates are not laws, since they have not been verified to the same degree, although they may lead to the formulation of laws.
- Laws are narrower in scope than scientific theories, which may entail one or several laws.
- Science distinguishes a law or theory from facts. Calling a law, a fact is ambiguous, an overstatement, or an equivocation.
- The nature of scientific laws has been much discussed in philosophy, but in essence scientific laws are simply empirical conclusions reached by scientific method; they are intended to be neither laden with ontological commitments nor statements of logical absolutes.

Cont’d

- Isaac Newton's law of gravitation is a famous example of an established law that was later found not to be universal—it does not hold in experiments involving motion at speeds close to the speed of light or in close proximity of strong gravitational fields.
- However, outside these conditions, Newton's laws remain an excellent model of motion and gravity.
- Scientists never claim absolute knowledge of nature or the behavior of the subject of the field of study.
- A scientific theory is always open to falsification, if new evidence is presented.

Cont'd

- Even the most basic and fundamental theories may turn out to be imperfect if new observations are inconsistent with them.
- It is critical to make every relevant part of research publicly available.
- This allows for and encourages peer review of published results, and it also allows ongoing reviews, repetition of experiments and observations by many different researchers.
- Only by meeting these expectations can it be determined how reliable the experimental results are for possible use by others.

Properties of a Scientific Law

- True, at least within their regime of validity. have never been repeatable contradicting observations.
- Universal. They appear to apply everywhere in the universe.
- Simple. They are typically expressed in terms of a single mathematical equation.
- Absolute. Nothing in the universe appears to affect them.
- Stable. Unchanged since first discovered (although they may have been shown to be approximations of more accurate laws).

Cont'd

- All-encompassing. Everything in the universe apparently must comply with them (according to observations).
- Generally conservative of quantity.
- Often expressions of existing homogeneities (symmetries) of space and time.
- Typically, theoretically reversible in time (if non-quantum), although time itself is irreversible.

List of Important Scientific Laws

- **Avogadro's Law**: Avogadros's law states that under the same conditions of temperature and pressure, equal volume of all gases contain equal number of molecules.
- **Archimedes Principle**: Archimedes Principle states that whenever a body is submerged partially or wholly in a fluid (either a liquid or gas), it experiences an upward thrust (buoyant force), whose magnitude is equal to the weight of the fluid displaced by it.
- **Boyle's Law**: Boyle's Law states that at a constant temperature, the pressure of a given quantity of gas varies inversely with its volume.

Cont’d

- **Coulomb’s Law**: Coulomb’s Law states that the force of attraction or repulsion between the force of attraction or repulsion between two charged bodies is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.
- **Faraday’s Law:** Faraday’s laws of electromagnetic induction consist of two laws. They are: Whenever the magnetic flux linked with a closed coil change, an induced emf is produced resulting in a current flow. The induced emf is directly proportional to the rate of change of flux.
- **Gauss’s Law**: Gauss’s Law states that the net electric flux associated with any closed surface is always proportional to total electric charge enclosed within it.

Cont’d

- **Joule’s Law**: Joule’s law states that when current ‘i’ passes through a conductor of resistance ‘r’ then the heat produced is directly proportional to the square of the current as well as its resistance.
- **Kirchhoff’s Law**: KCL or Kirchhoff’s Current Law states that the current entering the circuit of a node is equal to the current leaving the circuit at the node, provided that it is a closed circuit. KVL or Kirchhoff’s Voltage Law states that in a closed circuit, the sum total of voltages at the node is always equal to zero.

Cont’d

- **Newton’s Law**: Isaac Newton proposed three laws of motion, widely known as Newton’s Laws of motion.
- First law of motion states that everybody continues to be in a state of rest or in uniform motion unless acted upon by an external force.
- Second law of motion states that for an object with constant mass, the rate of change of momentum is directly proportional to the amount of force applied.
- Third law of motion states that for every action, there is an equal and opposite reaction.

Cont'd

- **Ohm's Law**: Ohm's law states that the current flowing through a conductor (between two points) will always be proportional to the voltage across them.
- **Snell's Law**: Snell's law states that the ratio of the sine of the angles of incidence and transmission is equal to the ratio of the refractive indices of the materials at the interface.
- **Laws of Reflection:** According to Euclid's Laws of Reflection- The angle of incidence is always equal to the angle of reflection. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.

Do laws change?

- Just because an idea becomes a law, doesn't mean that it can't be changed through scientific research in the future.
- The use of the word "law" by laymen and scientists differs. When most people talk about a law, they mean something that is absolute.
- A scientific law is much more flexible. It can have exceptions, be proven wrong or evolve over time.
- "A good scientist is one who always asks the question, 'How can I show myself wrong?'" Coppinger said.
- "In regards to the Law of Gravity or the Law of Independent Assortment, continual testing and observations have 'tweaked' these laws.
- Exceptions have been found. For example, Newton's Law of Gravity breaks down when looking at the quantum (sub-atomic) level. Mendel's Law of Independent Assortment breaks down when traits are "linked" on the same chromosome.

Hypothesis, Theories, and Laws

- Although many have taken science classes throughout the course of their studies, people often have incorrect or misleading ideas about some of the most important and basic principles in science.
- Most students have heard of hypotheses, theories, and laws, but what do these terms really mean?
- Prior to reading this section, consider what you have learned about these terms before.
- What do these terms mean to you? What do you read that contradicts or supports what you thought?

Cont'd

- Scientific Laws are different from Scientific theories in the sense that laws are narrower than theories.
- While a law tends to explain only what happens when two forces meet, scientific theories do tell us much more. A scientific theory explains the "What" and "How" of a natural occurrence.
- However, both scientific laws and scientific theories shall be considered as facts in common. Meanwhile, with ample evidence, a law or a theory can be falsified.
- Law and theory are two terms that are often used in context of scientific terminology. The main difference between a law and a theory is that a theory tries to explain the reasoning behind something that occurs in nature, whereas scientific laws are just descriptive accounts of how something occurs in nature.

Hypotheses and Theories

- A scientific theory is a set of statements that, when taken together, attempt to explain a broad class of related phenomena.
- Examples are spontaneous generation theory, biogenesis theory, and atomic molecular theory.
- However, while theories are tested, and thereby supported or contradicted, in the same way hypotheses are as a part of the scientific method, there is no requirement that a theory need be a well-supported explanation.
- We can now compare a (causal) hypothesis and a theory.

Cont’d

- Both actually represent the same type of scientific knowledge; that is, they are both explanatory in nature.
- In fact, the distinction between a causal hypothesis and a theory can be somewhat arbitrary.
- While a hypothesis attempts to explain a specific puzzling observation (or group of closely-related observations), a theory is more complex, more general, and more abstract and may even reflect the convergence of various hypotheses.

Difference Between a Hypothesis and a Theory

- A hypothesis is a suggestion of what might happen when you test out a theory. It is a prediction of a possible correlation between various phenomena. On the other hand, a theory has been tested and is well-substantiated. If a hypothesis succeeds in proving a certain point, it can then be called a theory.
- The data for a hypothesis is most often very limited, whereas the data relating to theory has been tested under numerous circumstances.
- A hypothesis offers a very specific instance; that is, it is limited to just one observation. On the other hand, a theory is more generalized and is put through a multitude of experiments and tests, which can then apply to various specific instances.

Cont'd

- The purposes of these two items are different as well. A hypothesis starts with a possibility that is uncertain but can be studied further via observations and experiments. A theory is used to explain why large sets of observations are continuously made.
- Hypotheses are based on various suggestions and possibilities but have uncertain results, while theories have a steady and reliable consensus among scientists and other professionals.
- Both theories and hypotheses are testable and falsifiable, but unlike theories, hypotheses are neither well-tested nor well-substantiated.

Unit tutorial questions

- Explain scientific models, theories and laws
- Outline some examples of Hypothesis in science
- What are the Key Points to consider when formulating a Hypothesis?
- Explain Null Hypothesis and Alternative Hypothesis
- Outline how to State a Null Hypothesis
- Mention some examples of Null Hypothesis Examples
- How does someone write a Hypothesis?

Cont’d

- Outline the differences between null and Alternative Hypothesis.
- What are the Characteristics of scientific models?
- Differentiate between null and Alternative Hypothesis
- Outline some characteristics of scientific models
- Why models are needed in science teaching and learning.
- How do you decide whether a scientific model is "right"?
- Outline some Advantages and limitations of Science Models
- How can we use models in teaching science?

THANK YOU