Co-funded by the
Erasmus+ Programme
of the European Union

# Science Bridging Course
# Unit P1 – Nature research - general concepts and laws

**In this chapter you will find out:**

- Common knowledge
- Natural laws and scientific laws
- Construction methods of scientific laws
- Hypothesis, its significance for law cognition
- The main types of scientific laws
- Laws and regularities
- Mathematic axioms

## Common knowledge

Common knowledge – spontaneously empirical – is such, which people observe every day. This knowledge is defective for it does not overstep direct perception limits of phenomena and objects. However, by common knowledge, a great deal of reliable knowledge is accumulated about the environment. The scientific knowledge itself evolved from everyday observations, from common knowledge, and at the beginning it did not overstep its limits. In the initial stage of science development, while special scientific research methods did not exist, scientists referred to direct observation. E.g., geocentric world system by ancient Greek astronomer K. Ptolemy (2$^{nd}$ century), which was supported by many astronomical observations (Egyptian, Babylonian, and especially Greek astronomers), mostly corresponded to direct sensual images, thus, knowledge based on direct sensual perception involves only visible, outer sphere (phenomena sphere) and does not reflect the object internal essential sides and relationships. Scientific knowledge acquisition is related to systematic experimental and theoretical research referring to certain methodology and concrete methods. Scientific research is purposive. Its results make the system of concepts, laws, and scientific theories. Science is systematic, consecutive, i.e., having a strict system based on a scientific method.
E.g., Euclid's geometry, Newton's classical mechanics, Einstein's relativity theory and other.

The main scientific theory elements, apart from facts and concepts, are scientific laws. After cognising the laws, science could pass from phenomena description, fact gathering and systematicity (17$^{th}$–18$^{th}$ centuries) – to their explanation and new law and new phenomena prediction.

### Natural laws and scientific laws

Nature, the world surrounding us, is the wholeness of differently interrelated things and phenomena. There exist essential relations in nature, determining the type of some phenomena, their functioning under certain circumstances. Such relationships are therefore called objective because they are characteristic of the nature itself, of the reality phenomena themselves, and do not depend on people's will and consciousness.

(The law of the Earth's rotation around the Sun, The law of the Earth's rotation around its own axis in 24hours, Gravitation law, the law of interaction of electric charges).

Any law of nature possesses a kind of necessity. The essential natural relationship (law) is also a necessary relationship. Universalism is characteristic of natural laws. Any law is characteristic of all without exception phenomena or objects of a certain type or kind: e.g., all material bodies are dependent on the law of gravitation, all objects having electric charge on – Coulomb's law, all conductors moving in the magnetic field on –Faraday's electromagnetic induction law and so on. If any objective law acts on the Earth, it means it acts everywhere, where there are more or less similar conditions to Earth, and similar objects, among which a regular relationship can occur. Phenomena are changing, they can be accidental or temporal, but the law remains. Thus, recurrence, regularity are very important traits of objective laws.
Scientific laws are reflection of natural laws. The content of scientific laws is objective, and the form is - subjective. Scientific laws are found. Researcher, having found laws acting in nature, explains them, then expresses and formulates in a certain language.

$$F = G\frac{M_1 M_2}{R^2}$$

*R*- distance between two bodies

$G = 6.67 \cdot 10^{-11}$ N·m²/kg² - gravitation constant

This law expresses the essential, necessary relationship – that all bodies in the world attract each other by force, which depends on their body masses and the distance between them. It is not easy to reveal the content of one or another objective law, and to formulate a scientific law conforming to it. Scientific and objective law conformity is determined by the complex structure of reality itself. The essential relations are internal, deep, and therefore cannot be perceived directly. In every science development stage, scientific cognition methods, ways, by which human mind penetrates into complex reality structure, are limited, imperfect. Thus, in the development of our knowledge and cognitive possibilities, scientific laws reflect objective natural laws more accurately and more exhaustively, i.e., they become more and more closer to objective laws, natural laws.

## Construction methods of scientific laws

Empirical scientific laws are derived referring to observations and experiments. Apart from empirical observations and tests, creating empirical laws, scientists make also use of preliminary speculation (hypothesis). It is incomparably more difficult to construct theoretical laws. It is known that scientific laws are expressed by scientific concept interrelationship form reflecting some or other essential object properties.

The process of scientific concept creation – is called **abstrahation**, and concepts having appeared in the process – **abstractions**. Abstractions are created by grouping things according to some property.

Another stage is – an operation of identification and separation. **Identification** is – finding of a certain property, more or less typical of all grouped things. **Separation** can be factual or imaginary.

The final abstract concept creation procedure is **verbalization**, i.e., giving a name or a word combination to the distinguished property. Concepts are – devices, which not only change their reflected things and phenomena, but also a lot of accumulated knowledge about them, they are cognitive outcomes. Concepts make a scientific language more informative, richer, enabling to fix and convey the knowledge with the smallest number of signs.

More distant than concepts are scientific laws. Creating them, idealisation method is of great significance. Correspondingly, by this method the reality is schematised because otherwise a scientific law cannot be established. Idealisation process is closely related to abstraction. Idealising, certain imaginary, idealised objects are created, which principally cannot be met in nature e.g., an absolutely rigid body, the ideal gas, an incompressible liquid, an absolutely black body, a point, a line and so on. Though such objects do not exist in reality, their imaginary construction is of great importance to cognition.

Idealised physical objects quite often are granted such properties, which are not found in nature i.e., imaginary. E.g., physicists refer to an ideal gas image, the absolutely elastic molecules of which are material points, and the potential energy of their interaction equals zero. There is no such gas in nature, however referring to this concept, the main gas laws are analysed in the kinetic molecular theory by Boyle, Charles, Gay-Lussac, and Avogadro. These laws are absolutely right only for the ideal gas, however, they can also under certain conditions describe the state of real gases. The main idealisation importance is that fictive, imaginary objects are treated as a means for really existing object and process exploration.

Thus:

1. Looking for the right outcomes in science, one cannot orient to simple experience.
2. A great importance of idealisation method to science.
3. Scientific law discovery and formulation is related to an idealisation process, and any idealisation is making of the reality primitive, simplified. These are ideal models of objective natural laws.

Laws, found in active science development stages, usually used to be formulated as absolute. Progressing of the sphere involving measurement and experiment, the law formulations used to be specified, providing certain conditions, therefore even the most precise, mathematically formulated scientific law is approximate.

We do not have to limit ourselves in generalisation and in finding a limiting case creating scientific abstractions. E.g., creation of particular concepts, which are called theoretical and hypothetical constructs is of great significance for physical science. E.g., electromagnetic field, electron, gravitation potential.

Thus, laws found by direct observation are called **empirical,** and laws created referring to data, which are obtained with the help of generalisation, idealisation processes and constructs, are called **theoretical** laws. Even though they are different, however, they are closely interrelated: theoretical law relationship with the empirical ones is more or less analogical of the latter relation to facts, which we face carrying out observations and experiments. Empirical laws generalise these facts, and they themselves in the same way are generalised by theoretical laws.

**Empirical laws can be derived from certain theoretical laws**.

E.g.

Newton's gravitation law (theor.) ⟶ Kepler's laws (empir.)

Maxwell's electromagnetism laws (theor.) ⟶ Faraday's and Coulon's laws (empir.)

Theoretical laws are important for the development of science also for that referring to them one can guess new, still unknown regularities in advance. So, theoretical laws give extremely thorough expression of the internal, essential objective world peculiarities.

## Hypothesis, its significance for law cognition

Hypothesis is an assumption. It can be right and completely wrong. Hypothesis is an intuitive scientific assumption, it is a discovery way of what is new, a science development method. Hypothesis method is basically the most important factual scientific material perception method. When the experimenters find facts, which these laws cannot explain, they need to look through current scientific laws (theories), and to raise hypotheses instead of them. Thus, hypothesis arises from contradiction between scientific law and experiment. Hypothesis raised by a scientist is grounded on newly found facts and has to be empirically tested. Hypothesis is said to be significant when breaking the frames of the formed images, it has to save them to a certain extent as well. Hypothesis sometimes moves away from traditional images so that it is perceived at first as something incredible.

So, science develops so that current knowledge and theories earlier or later start by all means contradict the assumptions, raised for the explanation of the new facts. All contemporary natural science fundamental laws and theories were hypothetical at first. Of course, they were researched long and multifacetedly by tests and by practice. To prove hypothesis is – to confirm it in practice.

E.g., K. Maxwell's assumption (1857), according to which Saturn's wings are formed from small, tiny bodies, was confirmed by spectral tests.

The rightness of hypothesis is ascertained according to how it conforms to observation, experience, practice data. However, practice criterion is not absolute but relative. People's practical activity, and especially scientific experiments constantly present new data, therefore, every scientific law found has to be confirmed once again. Therefore, new scientific hypotheses appear, prior visual modifications, current scientific laws are specified.

**Hypothesis and model**

Testing the hypothesis, very often difficulties emerge. In these cases, a very effective modelling method is applied. Models can be material or mental.

1. Material models. Using material bridge, ship, plane and other models, construction strength, usability are tested. Before transferring model acting regularities into objects, certain specifications and corrections are made, measurement results are recalculated.
2. Ideal models. Analysing any complex phenomenon, very often one has to construct mental visual models of some objects. According to resemblance to a prototype, ideal models can be distributed to:
   a) visual (iconic)
   b) symbolic

   Iconic model examples: ethereal mechanics models, gas models, planetary atomic models, structure and spatial molecular models, etc.
   Symbolic models: chemical structural formula.
3. Mathematical models. These are formula or equations, expressing object property and structure regularities. E.g., F=ma, Newton's $2^{nd}$ law. Mathematical modelling method is very widely applied in contemporary physics. Mathematicians very often prepare physical theory mathematical models in advance.
4. Theoretical models. Theoretical models are created for mathematical natural science (physics, astronomy and so on) abstract theory and formal symbolic logical – mathematical system interpretation.

Thus, modelling method is an important and effective testing way of scientific hypothetical statements.

## The main types of scientific laws

1. Individual (specific) scientific laws. Their acting area is narrow therefore, they belong to one of the natural (or social) sciences.
2. General law group consists of laws, the acting sphere of which is wide, they include a few close scientific spheres (e.g., the law of periodic chemical elements, energy endurance and transference law).

3. Universal laws. Laws expressing objective relations, acting in all existence and cognition spheres are attributed to them. They are researched by philosophy.

   Such distribution refers to ontological attitude (i.e., according to the type of the objects and their existence conditions).

   Gnoseological attitude (grounded on the level of the law cognition difference, on how exhaustively a particular scientific law reveals objective nature relations.

   1. Empirical laws.
   2. Theoretical laws.

Empirical and theoretical laws can be both partial and general, both dynamical and statistical

**Statistical and dynamical scientific laws**

Historically the first appeared dynamical laws (e.g., Newton's mechanics laws). Dynamical laws reveal themselves in comparatively simple systems, the condition of which is basically determined by internal relations of this system and a little bit – by external effects.
Differently from dynamic laws, statistical regularities cover the wholeness of objects, a huge quantity, and define the properties of this huge quantity as a wholeness. Such regularities reveal themselves in molecular-kinetic processes, in phenomena of radioactive splitting, mass service systems (communication, transport, etc.)

One can divide statistical laws into three types:

1. Laws describing object wholeness and cannot be applied to separate elements. E.g., the ideal gas parameters – $T$, $p$ and $V$ ($pV = RT$), suit for all statistical molecular ensemble, and lose any sense in respect of separate molecules.
2. Laws, which manifest themselves in that their reflected properties of the explored object wholeness are defined according to some average indicators of separate objects. E.g., average life expectancy under certain natural and social conditions, and population distribution according to gender; inheritance characteristics according to Mendel's laws; star accumulation property regularities; society development laws.
3. Laws, which unanimously are characteristic only of the wholeness of elements and can be separated into its elements only with a certain probability. Science encounters such laws in quantitative physics. The peculiarity of quantitative theory laws is that none of its objects is entirely individualised, independent from the whole world.

**Science and predictions**

Referring to science, future or current, but still not found phenomena are predicted, the ways and possibilities of the set goals are cleared. The aim to predict the future runs all through the whole human history.

The possibility to predict emerges from the scientific law essence itself because it reveals particular order, invariance of the object and phenomena essential interrelationship.

One can discern three scientific prediction types:

1. Prognostication of new phenomena, which have to emerge in future.
2. Earlier not known to science phenomena proving of existence in the past (e.g., geology, palaeontology, historical geography, etc.)
3. Ascertainment of now existing, but still not found phenomena, which cannot be directly observed or experimented.

From the logical point of view, a scientific guess, grounded on law, is similar to a scientific explanation. Scientific explanation is always more exhaustive than a guess because it is closer to description, direct information sources. Scientific ascertainment can be grounded on hypotheses as well. Hypothetical prognosis is also a testing means of the assumptions forming its basis. When such prognosis is confirmed by an experiment, practice, hypothesis becomes a scientific theory.

Extrapolation as a prediction form

Carrying out a prediction function, the science uses already known laws to such phenomena which are still unknown. Extrapolation - is the application of one scientific subject knowledge in a wider reality sphere, which science still does not know. Any scientific law has potential extrapolative possibilities. In science history, there is abundance of famous discoveries made by extrapolation methods. E.g., Newton's gravitation law, which at first was tested only for part of the planets, later it was successfully outspread for the whole Sun system, star movement, in our galaxy, and later also in other galaxies. A good mathematical extrapolation example is a discovery of electromagnetic waves carried out by Maxwell.

Thus, global extrapolation cannot be applied to scientific laws because they are formulated referring to limited historical practice and limited observation sphere possibilities of humanity.

## General concepts and laws

All laws are found when we explore the surrounding world. Here are some problematic aspects:

- walking in gas environment, it is easy (e.g., air) however a spaceship can burn in such an environment /atmosphere/;
- moving in a liquid is more difficult than in gases (e.g., when we dive);
- in order to move solid bodies, one needs to make one's way through/if the body is solid, so it becomes destroyed/

It took several centuries to understand such things. Physical and chemical world cognition methods and methodologies were created, exactly in the same way "macroscopic" and "atomistic" object research ways. Both of them continue to be used today, supplementing each other.

Today macroscopic is usually called phenomenological /operates units, the nature of which is not understandable/, and atomistic is usually called a microscopic method, which allows us to go deep into a particle interaction forming a system. However, the word microscopic is no longer in everyday use because a micrometre was the smallest unit after constructing a microscope. Today we can see objects smaller than nanometre. The formed terms are: "nanoscope", "nanoscopy", "nanotechnologies".

**Laws and regularities**

Natural phenomena, processes, animated nature are classified. Not for the things that somebody thought, but first of all, that we want to recognise the structure of the world. And in order to recognise it, we need to know three things (units):

1. Fundamental constant (light speed, electron charge, and other).
2. Conserved units, for which conservation laws are valid, and this is our world symmetry property (e.g., energy, motion quantity and other).
3. Various other units and parameters (e.g., distance, time, speed and other).

Equally, there exist three law groups /types/:
1. Regularities, which define tendencies, hierarchy of phenomena, unit interrelationship and so on. One can call them laws however, they are not exactly proved. Then we say that laws have established limits of validity (sometimes we do not want to say this) (e.g., Mendeleev's periodic system of elements).
2. Laws, which define particular relationship under specific and strict conditions and universal laws, defining accurate relationships. In this case, we do not have or do not know limits (e.g., law of universal gravitation).
3. There exist laws of generalisation, everyday language laws (e.g., nature abhors emptiness). In some cases, it has a deep meaning, in other cases we use it as a word pun.

The main laws, which form **the cognitive basis of science**, are:
1. Energy is not just coming out of nowhere and it is not just disappearing, only it can transfer from one form into another (energy conservation law).
2. Body motion can be changed only due to the acting force /motion quantity and motion quantity moment (rotation) conservation laws.

*Remark*: in order to understand this, special knowledge is necessary.

**Some words about mathematics**

What is this?
- mathematics is one of languages (prof. Gibsas);
- mathematics is servant of science;
- mathematics is queen of science;
- in every science there is as much science as there is mathematics in it, and the rest is picking herbs;
- mathematics – is similar to a French person, for whom you say something, he translates into his language, and something completely different comes out (Gėtė).

Thus, mathematics basically is a very simple science, which earlier was the occupation of philosophers. All mathematics science is made of a few postulates and axioms. The rest are derivative things, which are created. When the limit is overfilled – the revolution takes place in science and new mathematics is created.
E.g., Greek philosopher Euclid, after generalisation of all philosophers at that time, presented such postulates:
1. From one point to another one can draw a line.
2. One can extend a line segment to infinity.
3. A circle can be drawn with any centre and any radius.
4. All right angles are equal.
5. If a line crossing two other lines on one of its sides forms inner angles smaller than inner angles on its other side, so these two lines, if we extend them, will intersect on that side, where the sum of inner angles is smaller /however, if the angles are equal, the lines nowhere will intersect/.

However, a fellow appeared, who had a doubt about the fifth postulate because according to him space can be curved. A German mathematician Gauss, in order to calculate the area of dukedom, had to think a lot. A similar idea came to Kazan university professor N.Lobachevsky. He even was dismissed from duties because his theory contradicted the healthy mind. However, namely this theory helps to successfully analyse gravitation and Universe development problems.

**Axioms**:
1. If a=b and a=c, then b=c.
2. If a=b, then a+c=b+c.
3. If a=b, then a-c=b-c.
4. If a=/b, then a+c=/b+c.
5. If a=b, then 2a=2b.
6. If a=b, then a/2=b/2.
7. Congruent units /figures/ equal.
8. Whole is bigger than part.
9. Two lines do not embrace the space.

And that is all mathematics. None of mathematical operations or formulas can exhaustively describe what takes place in nature. Do not wish the results obtained under one type of conditions to apply for the other.

**Further reading, resources**:


Christian David (2018). Origin Story: a Big History of Everything. Little, Brown and Company. New York.

https://www.youtube.com/watch?v=9Efsz2hIpxE
https://www.youtube.com/watch?v=K6R4MHB2wlM
https://www.youtube.com/watch?v=XWc_CrtxS5Y