

**Degree IN TEACHER OF PRIMARY EDUCATION.**  
**Subject: Didactics of Experimental Sciences**  
**Course: 2019-20**

**Chapter 1. Nature of Science**




1.1. Introduction .....	2
1.2. Concept of Science .....	2
1.3. Scientific knowledge .....	3
1.4. Scientific laws, theories and models .....	6
1.5. Scientific Method .....	9
1.6. Scholar science. Didactic Transposition .....	12
1.7. Other types of knowledge .....	12
1.8. References .....	15

## 1.1. Introduction

Throughout human history, many ideas related to physical, biological, psychological and social development have been developed and tested. These ideas have enabled subsequent generations to understand more accurately and reliably the human species and its environment. The forms used to develop such ideas are forms of observation, thought, experimentation and attempt, which represent a fundamental aspect of the nature of science and reflect the extent to which it differs from other forms of knowledge. The union of science, mathematics and technology forms the scientific effort and makes it a success. Although each of these fields has its character and history, they are interdependent and mutually reinforcing.

## 1.2. Concept of Science

In definition, Science (from the Latin Scientia 'Knowledge') is the set of knowledge obtained through observation and reasoning, systematically structured and deduced from general principles and laws. Science is the eternal question of nature for a human. Although a theory assumes the hierarchy of a "Law", because the concordances do not seem to generate any doubt, it is not definitive but awaits the next amendment. One example is the laws of gravitation, which remained unquestionable for two centuries until the behaviour observed on the planet Mercury did not conform precisely to them. In this case, Einstein's theory of relativity helped explain this discrepancy, leading to a correction of the laws. Therefore, **science is the current verification without final certainty**. Science as a concept is known as systematised knowledge, developed through methodically organised observations, reasoning and evidence. Science uses different methods and techniques to acquire and organise the knowledge based on a set of objective facts accessible to some observers, and a criterion of truth and permanent correction. In that sense, we can divide Science as follows (scientific disciplines):

	Set the logical reasoning and work with ideas created by the mind ( <b>inductive logic method</b> ): mathematics, logic, etc...
	Their main purpose is the study of nature ( <b>scientific method</b> ): biology, physics, geology, chemistry, etc...
	Work with the aspects of the human being ( <b>method depends on each particular discipline</b> ): anthropology, economy, history, psychology, etc...

### 1.3. Scientific knowledge

Every science has its specific method, but we can find certain general characteristics. In this case, two main activities of science are the basis of the principles of scientific knowledge:

1. **Experience** is the main driving force behind the principles of scientific knowledge, but they can be hypotheses or postulates.
2. Based on the principles, science uses the **demonstration** to draw conclusions that form the scientific knowledge.

Scientific knowledge is a critical knowledge (informed), methodical, verifiable, systematic, orderly, unified, universal, objective, communicable (using the scientific language), rational, provisional and that explains and predicts facts using legislation.

#### **Some of the characteristics of scientific knowledge are:**

- It is **objective** because it is valid for all individuals and not only for one. It is of value and not individual or singular value. Get to know the reality as it is, the guarantee of objectivity are their techniques and methods of research and testing.
- Scientific knowledge is **critical** because it seeks to distinguish the true from the false justifying their knowledge showing evidence of this truth (**informed**).
- **Planning**, through the methods of research and testing, leads to scientific knowledge. The researcher follows procedures, develops its task based on a previous plan.
- **Verification** is possible through the adoption of the review of the experience. Verification techniques evolve.
- It is **systematic** because it is an orderly unit; new knowledge is integrated into the system, interacting with those that already existed. It is ordained because it is an aggregate of information, but a system of ideas connected.
- It is a **unified** knowledge because they are looking for a knowledge of the singular and concrete, but the knowledge of the general and abstract, or of what things are identical and permanent.
- It is **universal** because it is valid for all people without recognising borders or determinations of any kind, does not vary with the different cultures.
- It is **communicable** through the language of science, which is precise and unambiguous, understandable to any subject, trained personnel, who will be able to

obtain the necessary elements to check the validity of the theories in their relevant aspects and verifiable.

- It is **rational** because science knows the things through the use of intelligence, of reason.
- Scientific knowledge is **provisional** because the task of science does not stop; it continues its research in order to understand reality better. The search for truth is an open task.

Nowadays, scientific knowledge is a set of related facts, concepts, laws, theories and models related to each other trying to explain and interpret the aspects of the world that constitute its object of study.

**Scientific facts:** When we refer in everyday life to something that constitutes “a fact”, we want to indicate that it is something sufficiently verified, which it occurs in nature as a real and genuine phenomenon. Some examples of facts would be:

- *A magnet attracts a metal needle.*  
- *Sugar tastes sweet.*

- *A dog has four extremities.*  
- *Pure water boils at 100° C*

The science builds its knowledge about the world with the aspiration that it be true. In this sense, the “scientific facts” would constitute the fixed, permanent and independent knowledge of the subjective opinion of the scientists on a concrete part of the world. Therefore, discover a new fact is the most substantial contribution to the progress of science. However, this view of scientific facts is not the one currently held by most philosophers and scientists, because, usually, a fact - “gross fact”- is not the same as a scientific fact. Let us see the following example:

- ***Observe what happens when we add sugar into the water and leave it a certain time.***

*The gross fact is: “I see that the sugar goes to the bottom of the glass at the beginning and step by step it disappears until, at some point, the process stops the water looks the same as at the beginning”.*

*The scientific fact is: “Sugar dissolves in water”.*

- ***Observe what happens when we water a plant.***

*The gross fact is: “The water disappears”.*

*The scientific fact is “the plant absorbs the water.”*

**Scientific concepts:** They are the first link to try to explain and interpret the world. The introduction of these concepts leads to a structuring of the world. Thus, properties such as temperature or intelligence are not intrinsically qualitative or quantitative, but their character of the concepts we use when we talk about them. Moreover, it is necessary to use them following the profiles they adopt (Mosterín, 1987). The first thing that comes to mind is the great variety of scientific concepts that exist and their differences in nature. As an example, we can present the following list:

**Electron - Speed - Mountain - Fish - Moon - RNA - Gen - Erosion - Quark - Virus - Heat - Blackhole - Eye - Electric current Cell - Light - Force - Energy - Atom**

Some of them, like fish, force or heat come from ordinary language; while others, such as RNA or entropy, constitute creations linked to discoveries or theories.

### Different ways to classify the scientific concepts

**In the first place**, we can distinguish three broad groups of concepts:



**Qualifiers:** Refer to a particular group of objects or events with something in common. In ordinary language, nouns and adjectives correspond to classify concepts. In science, concepts are classified in sets called classifications (ways of ordering knowledge)

Examples of significant classifications in the sciences are the "periodic table of the elements" or the "Linnaeus classification of living organisms".

**Comparative:** Serve to establish comparisons. In natural language, they correspond to the comparative degree of the adjectives. These allow to differentiate more finely and represent a first step for the introduction of metric concepts. A typical example is the hardness used in mineralogy.



A clear example is the concept of hardness, applied to the domain of minerals.



**Metrics:** (also called quantitative concepts or magnitudes): Used to measure a certain entity, so include a unit to measure assigning real numbers (scalar magnitudes, mass or time) or vectors(vector magnitudes, force or velocity) to objects or events.

They are the original creation of scientific languages and have huge advantages over comparatives and qualifiers. The scientific vocabulary is much simpler, more precise and more manageable, and facilitates the search for scientific laws.

**In the second place**, we can differentiate between concrete and abstract concepts.

❖ **Concrete concepts:** Two types can be distinguished:

Type 1: Define attributes and examples that are observable directly with our senses; for example, insect, plant and mineral.

Type 2: Represent unobservable entities that are only accessible to our senses through instrumentation — for example, bacteria and viruses.

- ❖ *Abstract concepts*: Those that have no obvious examples or have defined details or attributes that are not perceptible. Examples, quarks, black holes, energy, density.

This classification depends on observation ability. Future technological advances could allow us, perhaps, to observe things that are not possible today. For example, viruses were unobservable entities before the discovery of the electron microscope, so in those times, so they had a classification as abstract concepts.

**In third place**, we can classify scientific concepts trying to differentiate between those that refer to **material entities or their properties and those that refer to processes**. The “matter” or “process” category includes most scientific concepts. For example, concepts included in the category of "matter" (animal, tree, water, mountain) can be said to have colour, weight, occupy space. From the concepts included in the category of "processes," we can say when they occurred, how long they lasted, what was the cause or purpose. For example, there is an alimentary relationship (process) in an ecosystem between animals, plants and medium (materials).

#### **1.4. Scientific laws, theories and models**

**Scientific laws**: In definition, a scientific law is a proposition that expresses a regularity of phenomena in nature, everybody accepts it and, generally, has a wide field of application. Laws express dependency relationships between events or phenomena. Trust in an accepted scientific law is such that, from that moment on, there is no doubt above all the law itself. Examples of scientific laws:

- ❖ “In chemical reactions, the total mass of the substances that react (reactants) is equal to the total mass of the substances (products) formed” (Lavoisier's Law).
- ❖ “Individuals resulting from the crossing of homozygous parents are phenotypically and genetically equal to each other” (1<sup>st</sup> Mendel's Law)
- ❖ “Everybody continues in its state of rest or uniform motion in a straight line unless it is forced to change that state by force” (1<sup>st</sup> Newton's Law).

A current and philosophically accepted view is that laws are constructions made by scientists that fit very well with reality, so it seems that nature manifests its order through them. Therefore, there are “laws of nature”, independent of our understanding. There are only laws that are known and practised, so it does not make any sense for a scientist to enunciate a law if the scientific community does not accept it and does not practice it (Echevarria, 1998).

Laws are abstractions of reality in which only the relevant factors of situations or phenomena appear. They can be represented by mathematical expressions that relate two or more variables ( $P.V. = n.R.T$ ) and formulated verbally. It is also important to emphasise that law is an advanced stage in scientific development since it relates concepts that have had to be studied and established previously.

**Scientific theories:** Although it is a concept on which there are many points of view, we could say that theories, according to Bunge (1985), the scientific theories are very compact systems of ideas (concepts, laws, hypotheses, logical relations).

We can highlight some examples of scientific theories that have exerted and exert considerable influence on the development of scientific thought:

- ❖ The heliocentric theory of Copernicus. The theory of universal gravitation of Newton.
- ❖ The Atomic theory of Dalton. The Evolutionist theory of Darwin.
- ❖ The cell theory of Ramón y Cajal. The theory about the Origin of Life of Oparín.
- ❖ The Relativity theory of Einstein.
- ❖ The theory of plate tectonics. The "Big-Bang" theory about the origin of the Universe.

Their ability to explain and predict phenomena in a specific field are some of the most valuable characteristics. The higher the field of application of a theory, the more it will be valued, as well as the simplicity in its formulation. All scientific theories are:

Partial as only deal with certain aspects of reality

Approximate, in the sense that they are not error-free

They are complex structures, not easily refuted by simple observations

They are valued for their ability to explain and predict phenomena in a given field.

In many cases, we use the words "model" and "theory" as synonyms. We will try to differentiate both terms in the following section. As Bunge (1985) says "theories are not models but include models."

**Scientific models:** We can use the term “model” in two senses in the field of empirical sciences:

*Model as “system in which what the theory says is fulfilled”.* (Mosterín, 1987).

In Science, it often happens that the system is intended to describe theoretically is enormously complicated (to construct a theory that helps us to explain and predict). Then, we follow an indirect path. We look at another system that is simpler or better known than the first, but that possesses some of its characteristics, that resembles it in some aspect that intuitively seems relevant to us. If we do not find such a system, we build it (with plastic, wood and steel or, at least, with the imagination). Then, we create a theory that adequately describes the operation of the simple system, which has a simple system by model, and, finally, we try to apply that same theory to the complex or unknown system.

*Model as “representation of something”* (Estany, 1993).

When using the term model as a synonym of "representation of something", we must distinguish between various types of representation.

- Scale models: They are a set of all the simulacra of material objects, both real and imaginary, that preserve the relative proportions. Examples of scale models are planes, miniature cars and reproductions of human organs used for teaching purposes.
- Analogue models: The fundamental objective of analogue models is to explain an unknown field by resorting to a known one. Sometimes they also have a didactic function, but unlike scale models, they require a more considerable resemblance, both in the elements of both structures and in their dynamics

The history of science provides abundant examples of the role of analogue models in scientific development:

- E. Rutherford and N. Bohr took the solar system as an analogue model to explain the atom, saying that the structure of the atom is analogous to the structure and functioning of the solar system.
- Ch. Huygens elaborated his wave theory of light with the help of suggestions derived from ideas, already familiar in his time, of sound as a wave phenomenon.

This meaning of model would be like the one proposed by Mosterín (1987) as "a system that serves as a model for a theory".



- Theoretical models: While some authors consider that "theoretical models" are the same as "theories", others consider that it is necessary to differentiate both terms. Thus, the "theoretical models" are "a more quantitative and exact theory than the original theory that established in more general terms".

However, **how is scientific knowledge produced?**

## 1.5. Scientific Method

The scientific method is the way ordered to proceed to the knowledge of the truth, in the area of a scientific discipline. It has the goal to determine the rules and testing of the research to achieve the scientific truths. It includes the study of how the human mind orders knowledge and extends it. Since we cannot identify and characterise a single scientific method, we are going to use the denomination of **scientific methodology** (and even methodologies) which is a more open term and that gives more idea of general procedures than of concrete steps or stages. We will try to highlight some general characteristics of the scientific methodology. We are going to do it on two levels:

*Level 1. Analyse of different parts of the fundamental processes*

❖ **Identify and define problems:** One of the essential aspects in scientific work is to delimit and define clearly and precisely the problem to be addressed, usually, part of problematic situations, open and, often, confusing. The clarification of these aspects requires, in many cases, an essential work of reflection and analysis based on the already existing knowledge and, on some occasions, on the observations made from reality.

❖ **Define hypothesis:** It is a statement that responds to a problem or question posed, and it has a background of truth based on theoretical and experimental foundations. Taking that statement as accurate, we can establish predictions about natural situations.

❖ **To experience:** It means studying the phenomena under conditions controlled by scientists. It allows focusing on the fundamental aspects of interest and avoiding or controlling everything that can be an accessory. It is the process to test the hypothesis is carried out. It requires to perform two types of tasks: first, the design of the experiment and second its execution. The design of the experiment supposes a mental process in which it is necessary:

a) *Analyse the situation focusing on the variables* that intervene or could intervene: the variable to measure (dependent variable); from which we find out its dependency

(independent variable) and which other variables can affect, and we do not want it to do so (variables to control). This type of analysis is called "variable control".

b) *Decide the actual conditions of the experiment:* materials and devices to be used, the number of observations.

The realisation of the experiment requires, in some cases, manual skills to handle the devices and instruments needed; as well as precision and rigour in the measurements and observations made. In other cases, wait for the results provided by the instruments used.

❖ **To get data:** *Observe.* It is a process in which we put into play our sensory and conceptual systems, so observation is dependent on our ideas. Even to use simple statements that do not seem to imply theoretical load (observational statements), the language of some theory (understood here as an idea) must be used (Chalmers, 1989). Scientific observation is used, in many cases, of devices capable of extending sensory sensations to surprise limits. The observation can be qualitative or quantitative. A quantitative observation is called measurement.

*Measure:* It is to compare an amount of one magnitude with another quantity of the same magnitude taken as a standard. The scientific community has agreed on the magnitudes considered fundamental and their units of measurement (International System of Units), so they form a universal language which makes measurement a process understandable to anyone. Even if the instruments are accurate and the person who uses them rigorously, the measurement is always associated with a degree of uncertainty or error (sensitivity of the instruments and errors of the users), so one can never consider any rigorously accurate quantitative observation, and the qualitative observations are even less so.

❖ **Record and classify data:** Data is the product of qualitative and quantitative observations. The registration of the data can be done in different ways: written descriptions, drawings, numerical tables, diagrams, maps. There is no one proper way to record the data. It will depend on the type of data, the specific circumstances of collection, and what they intend to do with them. It is important is to collect the data as we produce them. Classification means ordering the data. Scientists classify in order to simplify the object of study and present the data available in some way that allows us to think better about them and can extract guidelines or general ideas. The researchers establish the criteria to perform the classifications. These criteria can change if they change the knowledge or the points of view adopted and, therefore, the classifications are not static and modifiable as a result of the changes of criteria.

❖ **Interpret data:** *Induce and Deduct:* These are fundamental logical processes of thought in the construction of scientific knowledge. An *induction* is an affirmation (about the properties, behaviour) carried out on all the elements or individuals of a group based on the knowledge of only a part of the individuals of that group. On the opposite, a *deduction* is an affirmation (about the properties, behaviour) of an object, individual or situation, based on the rules of properties, the behaviour of the group to which that element belongs. For example, given the fact that metals expand when heated, it is possible to deduce the fact that railway rails (made of metal) will also expand with heat.

❖ **Communicate:** Science is a social activity and, therefore, communication plays a fundamental role in so that generated knowledge by scientists (private science) can become socially accepted as scientific knowledge (public science), which we colloquially understand as “Science”.

*Level 2: Analyse a model that explains what the research process is.*

The research process: Scientific research is an extraordinarily complex collective process involving some or all the basic scientific processes described above, as well as other factors related to personal, scientific and social issues. As highlights of scientific research can highlight the following:

A. Identification and definition of problems (research questions).

Presentation of clear and precise problems starting from initially more open and confused situations.

The formulation of precise questions and/or problems is based on the knowledge available at that time or problems generated in previous research.

B. Once the problems or research questions have been raised, the research phases are:

- ❖ Formulation of hypotheses (verified predictions based on theoretical and/or experimental foundations)
- ❖ Strategies for testing hypotheses (design and realization of experiments).
- ❖ Interpretation of the results of the research (contrast the results with the hypotheses).
- ❖ Communication of results and exchange with other research teams.

C. Conclusions of the research process.

They may simply contribute to falsify or verify the hypotheses raised or, modify beliefs or attitudes of the scientific community and enable technical applications and generate new problems.

In definitive, proper research is the one that answers a question and raises some new ones, and, the conclusions lead to a re-thinking of the research process in one or some of its phases.

## **1.6. Scholar science. Didactic Transposition**

### **Scholar science**

When we refer to science in the context of formal education, we talk about scholar science and, that it is different both to the science of scientists and to common knowledge. The three types of knowledge, the daily, the scientific and the scholar, are differentiated by the objectives they pursue, the world they are interested in, the methods used for their construction and the criteria for their validation. Scholar science is a social product, institutionalised and regulated, whose main objective is to promote the scientific education of students of all educational levels. There are different ways of understanding scholar science. Here we will consider it as an evolutionary process according to which teaching science implies, among other aspects, establishing bridges between scientific knowledge, as expressed by scientists through their writings, and the knowledge that students can build, initially from their daily knowledge.

### **Didactic transposition**

The process of selection of school content is called "didactic transposition" and does not consist, in the case of science, solely and exclusively in a simplification of scientific knowledge to make it available to students of different educational levels. It involves a complex process of restructuring scientific knowledge involving various factors as the science of scientists, the characteristics of students and social requirements. The recognition of this process by teachers is a vital aspect of the teaching of science. It is about defining a set of essential knowledge in science and useful for students to explain and interpret the world around them (see, for example, the differences between the classifications of the animals in the textbooks and the zoologists one). Scholar science curriculum usually reflects those aspects that are considered socially relevant at the time of their preparation, not only issues considered strictly scientific but also specific socio-cultural requirements that society poses to the school. For example, society currently considers that the school should contribute to the development of certain types of values as those related to an environmental ethic.

## **1.7. Other types of knowledge**

The term "knowledge" is the ability to act, process and interpret information to generate more knowledge or give a solution to a given problem. The knowledge can be interpreted and understood by human beings and even by machines through intelligent artificial agents. Scientists and researchers define this term in two ways: as a mental representation of reality

and how the information can be transmitted from one entity to another. According to these definitions and the methods used to construct or to generate knowledge, the division is:

***Intuitive knowledge:*** Intuition is an arbitrary verdict from the cognitive experience. In definition, intuitive knowledge is the immediate apprehension of internal or external experiences in their experimentation or perception. To this apprehension, the metaphysicians call it spiritual, because it is sensitive, but we know that there is, so it also becomes not deniable. How the human being learns by three elements of her psychic structure, the reason, the knowledge, the will, the judgments of this knowledge become independent and personal, even when there is a general cognitive awareness in the human being. In other words, it is the knowledge acquired by nature, and everyone has in one degree or another. The intuition works as a principle to the solution to a problem or situation based on the informal sector and rapid processing of cognitive experiences and. Science is full of intuitions, some that lead to success, others that lead to the error but that produce a new experience that subsequently will be codified in a new intuition now more successful.

***Empirical knowledge:*** The empirical knowledge is the knowledge based on experience and, ultimately, in the perception, because it shows what exists and its characteristics, but it does not explain that something must be in a certain way. Therefore, empirical knowledge comes from the observation of our environment, but not everything we learn is by empiricism, since, after the observation of the phenomenon, the human being tries to reproduce it and control it, and from it, scientific knowledge appears.

***Religious or traditional knowledge:*** Religion is an element of human activity that usually consists of beliefs and practices on issues of existential type, moral and supernatural. There is the talk of "religions" to refer to specific forms of manifestation of the religious phenomenon, shared by the different human groups. Some religions are organised rigid forms, while others lack formal structure and integrate into the cultural traditions of the society or ethnic group. The term refers to both the personal beliefs and practices how to collective rites and teachings.

***Philosophical Knowledge:*** It comes from the systematic and methodical reflection about ultimate truths of human existence and of everything that surrounds us. Initially, the philosophical knowledge covered or understood the knowledge about the nature of the world and of human beings, but to the extent that the philosophy and philosophers were discovering laws of nature, they were separating from the philosophy to be independent knowledge

systems as autonomous disciplines. These went on to become a separate scientific discipline of philosophical thought in such a way that although the philosophy represents the search of right knowledge, it does great fundamental truths of life and the universe through methodical and systematic reflection, while the scientific knowledge refers to more specific aspects. The philosophical knowledge is permanently open to revision; at the same time, it often offers more than one vision of the same phenomenon under study, and contradictory.

## 1.8. References

Bunge, M.; 1985. La investigación científica. Ariel, 2ª Ed. Barcelona.

Chalmers, A., 1989. ¿Qué es esa cosa llamada ciencia? Siglo XXI de Editores, S.A., Madrid.

Echevarría, J. 1998. Filosofía de la ciencia. Akal, Madrid.

Estany, A., 1993. Introducción a la Filosofía de la Ciencia. Crítica, Grupo Grijalbo-Mondadori, Barcelona.

Izquierdo, M. y Rier, I. (1997) “La estructura y la comprensión de textos de ciencias”. Alambique, 11:75-85.

Hodson, D.; 1988. Filosofía de la ciencia y educación científica, en Porlán, R.; García, E. y Cañal, P. (comp). Constructivismo y enseñanza de las ciencias. Diada Editoras. Sevilla, pp. 5-21.

Jiménez, P. y Sanmartí, N.; 1997. ¿Qué ciencia enseñar?: objetivos y contenidos en la Educación Secundaria, capítulo I en Del Carmen (coord.): La enseñanza y el aprendizaje de las Ciencias de la Naturaleza en la Educación Secundaria. Horsori/ ICE de la Universitat de Barcelona.

Kuhn, T.; 1971. La estructura de las revoluciones científicas. Fondo de Cultura Económica, México.

Mosterín, J.; 1987. Conceptos y teorías en la ciencia. Alianza Universidad, 2ª Ed., Madrid

Pujol, R.; 2003. Didáctica de las ciencias en la educación primaria. Síntesis Educación, Madrid.